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INTRODUCTION

by

PIERRE AUGER

Dr. Auger, Professor of Physics at the Sorbonne, and Director of Unesco's Department of Natural Sciences, was Secretary-General of the International Conference on Radio-isotopes in Scientific Research, organized by Unesco and held in Paris from 9 to 20 September 1957.

Molecules and atoms have now become the chief actors in the world of science. Not only has physics given us such insight into the structure of matter that it can be analysed so as to distinguish even between the nuclei of atoms, but real progress in chemistry, biology and astronomy itself is dependent on a better knowledge of the laws governing the microscopic world of elementary particles.

A striking demonstration of this aspect of the evolution of science was afforded by the International Conference on Radio-isotopes in Scientific Research, convened by Unesco in Paris in September 1957. Over two hundred papers were presented and discussed; they dealt with the results yielded by methods based on the properties of natural or synthetic radio-isotopes when applied to all branches of the natural sciences, from the physics of solids to the mechanism of plant photosynthesis.

Indeed, no experimental method has so rapidly been put to use in every branch of science since spectroscopy met with its extraordinary success. For the past hundred years, spectroscopy has provided a means of studying phenomena ranging from certain chemical reactions during cell division to the movements of the stars, but these studies were confined to the field of electronics, that is, the outer sphere of molecules and atoms. Methods based on radio-activity, on the other hand, are the key to the identification of the very nuclei of atoms.

The term 'radio-isotopes', which has recently come into popular favour, is merely a more precise way of defining certain chemical elements, covering not only their chemical properties but also the radio-active properties of their nucleus. This radio-activity affords a means of tracing the atoms concerned throughout their physico-chemical history and, in particular, by introducing them into certain molecules, of 'tagging' the latter. It is easy to see how extraordinarily useful it may be to be able to identify and trace certain atoms or molecules in their movements and transformations whenever any major changes occur at the molecular and atomic level. As mentioned

before, these new developments are having repercussions on all branches of modern science.

The scientists who met together in Paris did more than acquaint one another with the latest results of their research; they also endeavoured to explain them to research workers in other branches of science and even to the general public. This was the purpose of the evening lectures arranged by Unesco to give some of the most eminent members of the conference an opportunity of describing the consequences of scientific progress in various fields of very broad general interest. Some of these lectures, bearing more particularly on the economic and social consequences and aspects of the use of radio-isotopes, have been assembled in the present issue of *Impact*.

THE FUTURE OF ATOMIC ENERGY

by
SIR JOHN COCKCROFT

Sir John Cockcroft, O.M., F.R.S., who was President of the Conference, is Director of the Atomic Energy Research Establishment at Harwell (U.K.). He was awarded the Nobel Prize in Physics in 1951.

At an evening meeting of the 1955 Geneva Conference on the Peaceful Uses of Atomic Energy, I was bold enough to deliver an address on the future of atomic energy. Tonight I have been asked to appear once again in the role of a prophet, and I will try to describe how these visions of the future have changed during the last two years.

EXPANDING ENERGY NEEDS

At Geneva our economists and statisticians predicted that the world's total energy requirements would increase by about one and a half times by 1975, and by three times by the year 2000. To meet this enormous increase in the demand for energy, rising to the equivalent of 7 milliard tons of coal a year, it will be necessary to make the fullest use of potential hydroelectric resources, which are capable of doing the work of 1 milliard tons of coal a year, and also to call on nuclear energy to provide electricity supplies equivalent to the work of 2 to 3 milliard tons of coal a year, leaving coal and oil to provide the rest. By 1975 electricity production was expected to increase about four times over the 1955 level—from 1,500 milliard to 6,000 milliard kWh—requiring the equivalent of 3 milliard tons of coal.

During the last two years the countries of Western Europe have taken stock of their energy requirements and have realized that, since their coal production is expanding very little, they would require very large increases in imports of coal and oil. Thus, if nuclear energy were not developed, the six Euratom countries' bill for fuel imports would rise from $2,000 million a year in 1957 to $6,000 million in 1975. Without the development of nuclear energy, fuel imports for electricity production in the United Kingdom might increase by anything up to £350 million.

The Euratom countries have therefore prepared a target plan for installing 15,000 megawatts of nuclear power stations by 1967. The United Kingdom Government has decided to build nuclear power stations having a capacity of 5,000 to 6,000 megawatts by 1965, to do the work of 18 million tons of coal a year and thus to reduce fuel imports correspondingly. By 1975 the Euratom plan would save 100 million tons of coal equivalent a year, and the United Kingdom nuclear power development may well save 40 to 50 million tons of coal equivalent.

The situation in other Western European countries is rather similar, though nuclear power will not become important until hydroelectric supplies have been fully utilized. Thus Sweden now obtains three-quarters of its energy from imported fuel at a cost of 17 per cent of its total import bill. On the other hand, Swedish hydroelectric resources will not be fully exploited until 1968-70, so that nuclear power development is not so urgent.

A similar situation prevails in the Soviet Union and the United States of America. In these two countries abundant supplies of conventional fuels and unexploited hydroelectric capacity will delay very large-scale exploitation of nuclear power. The latest forecast predicts 3,000 to 4,000 megawatts for the U.S.A. by 1965, and 1,500 megawatts for the U.S.S.R. by about 1961.

In Asian countries, Japan is in a situation similar to that of Western Europe: India has great resources of hydroelectric power and will only require nuclear energy in regions remote from these resources; some Middle East countries, such as Iraq, have immense indigenous oil supplies and are hardly likely to be interested in nuclear power during this century.

In Africa the great hydroelectric schemes at Owen Falls and Kariba Gorge, and the Volta scheme in Ghana, together with abundant coal in other areas, mean that nuclear power applications will be limited in scope during the next two decades.

In Oceania, hydroelectricity is abundant in the South Island of New Zealand, and coal is abundant in many parts of Australia; however, nuclear power may become important in mining areas and in South Australia by 1965.

By 1965 then, nuclear power will be developing rapidly in Western Europe, and more slowly elsewhere. In Great Britain the nuclear power plan is already being translated into concrete and steel, and three nuclear power stations of about 300 megawatts output each are being built for completion in 1960-61. A Somerset station of 500 megawatts output will follow by 1962, and at least eight further great stations will be ready by 1965.

In these plans, and those announced in other countries, two types of nuclear reactors seem likely to play the major role. Britain is basing the first stage of its programme on the gas-cooled graphite-moderated reactor; the

U.S.A. and the U.S.S.R. are building their first full-scale nuclear power stations with pressurized water reactors.

NUCLEAR POWER COST

The first U.K. nuclear power stations are characterized by rather high capital costs, but low fuel costs resulting from the use of natural uranium. The U.S.A. pressurized water reactors have lower capital costs, but higher fuel costs due to their use of the more expensive enriched uranium fuel. The relative economies of the two types of power units vary in different countries, depending on the cost of labour, the interest charges and the method of financing. Thus the gas-cooled graphite-moderated reactor will produce electricity more cheaply in the U.K. than it would in the U.S.A. Capital costs of this reactor in particular are, moreover, likely to fall rapidly with foreseeable increases of power output and fuel temperatures of reactors, and Sir Christopher Hinton has predicted that nuclear power costs will fall by 30 per cent in the decade 1960-70, whilst the cost of power from coal-fired stations may rise by up to 10 per cent in this period if present trends continue.

If we turn from predictions to actual facts, we in Britain have by now had 15 months' experience of operating the Calder Hall nuclear power station, which produces 70 megawatts of electricity using two nuclear reactors as a source of heat. The experience has so far been very good, better indeed than in the case of most conventional power stations. There is, in fact, little to go wrong in the nuclear parts of a power station except the uranium fuel elements. Any maintenance trouble usually comes from conventional components, such as pumps, or from mechanical gadgets.

The fuel costs of nuclear power stations depend on the amount of heat which can be extracted from each ton of uranium before the chain reaction runs down. We base our cost forecasts on the assumption that from each ton of uranium we shall be able to extract the heat equivalent of 10,000 tons of coal in the 1960 stations. This depends on fuel elements retaining their integrity throughout a life of four to five years. Each Calder Hall reactor contains 10,000 fuel elements; so far only three fuel elements have developed faults—usually tiny cracks in the walls of the sheathing metal. These cracks lead to a small escape of radio-activity into the gas stream; this is detected quickly, so that the fuel elements can be changed when necessary. So far as it goes, the Calder Hall experience augurs well for the future of nuclear power development and translates dreams into realities.

We can also foresee the possibility of steadily improving this type of nuclear power station. Conventional engineering improvements will play their part in increasing output and lowering capital costs between 1960 and 1965. The increase in output from the 70 megawatts of Calder Hall to the 500 mega-

watts of the 1962 Somerset station is an example of this process. We can also foresee a further major improvement in performance by changing from metallic fuels to ceramic fuels, such as uranium oxide, by the mid-1960s. These latter fuels have the great advantage of withstanding higher temperatures, and also of resisting radiation damage, better than metal does. These two factors should enable heat ratings and efficiency and burn-up to be increased, leading to lower capital costs and lower fuel costs.

We can also foresee that, by 1965-70, recycling of plutonium fuel will be established, and that plutonium may be recycled with thorium as a fertile material, which will lead us into the thorium fuel cycle. This cycle is likely to have better nuclear characteristics for thermal reactors than the uranium fuel cycle. Our experience of radiation damage of plutonium-enriched fuels in some carriers has been very favourable.

We can then predict that, from 1970 onwards, thorium resources will powerfully reinforce the energy available from uranium resources. At the Geneva conference, Mr. Jesse Johnson said that in seven countries alone there was available a million tons of uranium, and that the price of uranium oxide would fall towards $10 a pound by 1965. Since then, many more important uranium deposits have been found, especially in Canada, and supplies of well over 30,000 tons a year of uranium oxide are assured, whilst prices seem likely to fall even lower than Mr. Jesse Johnson's $10 a pound.

If the Euratom plan is fully implemented, the annual burn-up of European and United Kingdom nuclear power stations in 1975 might require about 5,000 tons of uranium a year, if plutonium recycling is in full swing by then. Another 5,000 tons of uranium a year would provide for the initial fuel charges of about 5,000 megawatts of new installations a year.

These requirements would be reduced by improvements in the neutron economy of reactors or by the successful introduction of breeder reactors. Britain is now building at Dounreay, in the North of Scotland, a 60 megawatt (thermal) fast reactor, an experiment designed to solve the technological problems of highly enriched fuel breeder reactors. We expect this to be commissioned in 1958, and we shall accumulate experience in the formidable technological problem of the fast reactor during the course of the following two or three years. If we can solve these problems economically, we would expect that plutonium from our thermal reactor power stations would begin to be used as fuel for breeder power stations by the 1970s, and that the installation rate of breeders would then be adjusted to the output of the thermal stations.

SHIP PROPULSION

I have so far spoken of the development of nuclear power in large blocks. But the application of nuclear power to ship propulsion and to smaller land stations is also making progress. The United States nuclear submarine, Nautilus, has a remarkable record of trouble-free performance in steaming over 60,000 milles; and the U.S.A. is already embarking on the construction of a 20,000 ton combined passenger-cargo ship powered by a 20,000 shaft horse power nuclear propulsion unit of the Nautilus type. The U.S.S.R. is constructing a nuclear propelled icebreaker.

In Britain, with only modest supplies of enriched fuel, we are studying the application of reactors using natural uranium fuel or fuel of only low enrichment, since these reactors seem more likely to be economic than those using highly enriched fuel. A tanker of the 40,000 to 60,000 ton class is the most likely candidate for quasi-economic nuclear propulsion, since it has a high load factor. In addition then to the large nuclear propelled navy of the U.S.A., we can foresee demonstration or prototype commercial ships sailing the ocean by the mid-1960s, but no great change over to commercial nuclear propulsion is likely till the 1970s.

These comparatively small power units will find applications in land stations in the 20 to 30 megawatt output range. A large part of Britain's exports of conventional power units at present lie in this range. If 20 megawatt nuclear power stations can be developed to produce power at about 1d. per unit, with a typical load factor of 50 per cent, they would find a ready use. I think the prospects for these power units will be good by the mid-1960s. This type of power station will find applications in the so-called underdeveloped countries and remote mining areas, where power costs are abnormally high at present—as much as 3d. per unit in places like Broken Hill (Australia).

THERMO-NUCLEAR POWER

If we look still further ahead, we see the glittering prospects of releasing energy from controlled thermo-nuclear reactors, properly known as fusion reactors. The principles of a thermo-nuclear reactor are well known. If deuterium or a mixture of deuterium and tritium is heated up to a temperature of 2 or 3 million degrees, nuclear fusion reactions will occur, helium will be formed and neutrons will be emitted. The gas can be heated up and made highly conducting by a powerful electrical discharge either in a torus or in a straight cylindrical tube. The technical problem is to insulate the hot plasma from the walls of the container vessel so that conduction losses become unimportant. The experimenter is helped by the constructive action of the

magnetic field produced by the current carried by the plasma. This pinches the plasma into a filament. The filament, however, is unstable—it tries to turn itself into a helix and wriggles, so that the experimenter has to overcome this by using additional magnetic fields as stabilizing mechanism.

To produce a practical thermo-nuclear reactor, however, the energy output must exceed the energy input. Radiation losses increase slowly with temperature, whilst the release of fusion energy increases very rapidly. For energy output to exceed energy input, temperatures of about 50 million degrees are required. This is likely to take some time to develop. Neutrons have already been observed by several groups of experimenters working with straight tubes in the U.S.S.R., the U.S.A. and in the U.K., but they have been shown to be due to conventional accelerating processes caused by strong electric fields and not to high temperature plasmas. It is sometimes difficult to be sure of the origins of neutrons in this work; nevertheless it is likely that temperatures of a few million degrees will be achieved shortly, and, with these, fusion reactions will be produced by high temperature plasmas. In Britain we have recently put into operation a torus known as ZETA, with the object of reaching temperatures of several million degrees. Promising results have already been obtained, but we require time for their interpretation.

SAFETY PROBLEMS

The large-scale development of nuclear power in the world presents us with new safety problems, and problems of radiological control. These are now receiving a good deal of attention in Britain and the U.S.A. Designers and operators of nuclear reactors are very conscious of the fact that millions of curies of fission products are locked up in the fuel elements, and that overheating and melting of the fuel element would release these fission products into the reactor circuit. The reactor design and codes of operation must ensure that temperatures cannot rise sufficiently to melt fuel elements; and that even if melting takes place, the products are contained within the reactor circuit or a containing shell. Research on safety problems is important and is being carried out intensively in the U.S.A. and the U.K. We also have the problem of concentration and storage of the radio-active waste products from the chemical separation plant where fuel elements are processed. In Britain we now evaporate our waste products to small volume, and store these in stainless steel tanks. By 1960 we hope to be extracting the long-lived radio-caesium to produce radio-active sources on the megacurie scale for use in industrial processes. This will help to solve the problem of storing the remainder. Other fission products, such as the radio-active gases, are beginning to be extracted, stored and used for industrial purposes, thereby helping to reduce the contamination of the atmosphere.

THE USES OF ISOTOPES

The use of these large sources of radio-isotopes is now being studied actively in many countries. In Britain we have founded the Wantage Radiation Laboratory as a close satellite of Harwell, to carry out such studies. The laboratory is now equipped with sources of radio-cobalt of up to 10,000 curies, and it is hoped in due course to equip it with radio-cobalt sources of half a million curies, and later on with still more powerful radio-caesium sources. These will be available for research by industry, government departments and Atomic Energy Authority staff, for applying radiation to chemical processes, to food preservation, to sterilization and other problems.

At the Wantage laboratory we are investigating many possible uses of radiation in industry. Most of such work has so far been done in the U.S.A., where millions of dollars have been spent on investigating food preservation or the extension of storage life of food. It has been found that the storage life of bacon, ham and sausages can be increased by four or five times. To increase the storage life further would necessitate such big radiation doses that unwanted side effects, such as unpleasant taste and flavour, would appear. Scientists working on food preservation are now more and more adopting combined methods of preservation, using radiation plus light cooking of the food, or an addition of anti-biotics. These combined operations look very promising.

Radiation may also contribute to insect control. We heard at the Geneva conference of the spectacular work on the elimination of the screw worm by the irradiation of the male flies. We are working now on grain disinfestation, a serious problem in some of the grain producing countries. Although doses of 50,000 roentgens are necessary to kill insects, much smaller doses suffice to make their eggs infertile.

Radiation is already playing a new role in sterilization. Bone and tissue used for transplanting are being sterilized in that way in at least one country (U.S.A.), and the use of radiation to sterilize hospital blankets, sutures and bandages is being actively investigated at Wantage.

Radiation may be of great importance in the treatment of anti-biotics. The dose to reduce bacteria by 10^8 is of the order of 2×10^6 roentgens. This dose produces a temperature rise of only 1° to 2°C. and is therefore an ideal method for the treatment of heat-sensitive drugs, like penicillin, which at present have to be filtered from bacteria and afterwards aseptically treated. Radiation might be used in the final packaging so as to give safer drugs. Experiments have shown that the amounts of radiation necessary do not influence the potency of anti-biotics like penicillin, streptomycin and others.

The importance of radiation in plant breeding is emphasized in a recent report of the Economic and Social Council. The mutations induced by radiation include both gene changes and chromosomal alterations, and are in

general of much the same character as naturally occurring so-called spontaneous mutations. In both cases they are mostly deleterious, and only a small proportion—perhaps one in a thousand—are potentially useful. Yet it is on the basis of those relatively rare favourable mutations that all living organisms have evolved through the ages, firstly through the agency of natural selection, and subsequently, in the case of our domesticated crops and livestock, through selection exercised by man himself.

The contribution of radiation in plant breeding consists in vastly increasing the frequency of appearance of mutations—by fifty or a hundredfold or more—and so providing a relatively simple means of greatly expanding the variability available to the plant breeder for selection. To this extent it is a most valuable addition to the normal procedure of collecting and maintaining a representative sample of the natural variability of the crop for use in breeding programmes.

Remembering that this entirely new approach was initiated less than thirty years ago in Europe, and only a few years ago in the U.S.A., the practical successes that have already been achieved are impressive. In Sweden an improved variety of white mustard of superior yield and oil-content, and a more uniformly ripening, early, high-yielding variety of summer oil rape are already in use, whilst a variety of cooking pea with distinctive fruiting habit and higher yield has recently been released for use in 1957.

In addition, many promising new types obtained by irradiation of barley, wheat, oats, soya bean, flax and many other crops are under test in Sweden. These new types include short and stiff-strawed types of cereals more resistant to lodging and thus better able to make economic use of fertilizer dressings as well as being better adapted to mechanical harvesting; types with shorter or longer maturity period; and types with changed ecological adaptation in relation to such features as the amount of rainfall. Other countries reporting promising mutations in a wide range of agricultural and horticultural crop plants are, in particular Germany, but also Austria, Belgium, Finland, France, India, Japan, the Netherlands, Norway and the United Kingdom which so far, however, have had smaller irradiation programmes.

Almost all these European and Asian accomplishments have been achieved through the use of X-rays. It is only from the U.S.A. that extensive accomplishments with radiation derived from atomic energy sources have so far been reported, but there also X-rays have been extensively used. The first new strain developed by irradiation to go into production in the U.S.A. is a bush type of bean derived from a vine type. It was developed from material treated with X-rays in 1941 and was released for the 1957 crop season. Its upright open habit makes it more tolerant of wet weather than the original type, and less subject to disease and rotting; it will also be adaptable to mechanical harvesting.

Most of the characters already mentioned are controlled by only one or a

few genes of relatively large effect. Quantitative characters, such as yield, and quality are determined by a large number of genes of individually small effect. Particularly extensive work with peanuts in the U.S.A. has already demonstrated the possibility of increasing the genetic variability in respect of yield through irradiation, and accumulating favourable mutants into a more productive type by subsequent selection. These achievements demonstrate that the induction of useful mutations by radiation is possible with regard to many kinds of characters of diverse genetical types in a wide range of crops.

In addition to its general value in providing a ready means of furnishing new breeding material, radiation may on occasion make a unique contribution to crop improvement by raising the frequency of occurrence of certain extremely rare types of mutation to a level where they can usefully be employed by the plant breeder to achieve results that would be well-nigh impossible by other procedures. For example, it may provide a means of separating favourable and unfavourable characters that are genetically so closely associated that, for all practical purposes, they are usually regarded as inseparable. A close association of this nature between resistance to a particular disease and susceptibility to another in oats has already been broken in radiation experiments in the U.S.A.

A very interesting new approach is the attempt to achieve cross strains from normally incompatible parents. This is done by irradiating the pollen of one strain. Some success has been achieved already, and it is likely that this method may yield most interesting new strains.

Some of the physical changes which radiation may produce are well known. Polyethylene can be cross-linked by radiation, and the resulting polymer can stand up to higher temperatures. Polyethylene melts at 110°C., but when irradiated with doses of roughly 10^7 roentgens, can stand up to 150°C., a very important feature for the electrical cable industry.

At present industry is trying to find new useful radiation-induced polymerization products. Vulcanization of rubber is generally carried out by using sulphur as the link between different atoms. By using radiation, this link may be established without introducing a new element, and the resulting product has therefore a much better temperature resistance. Tyres are claimed to last longer. Radiation energy may be used to make chemicals which are at present produced by high pressure and temperature, or may even be able to give us new compounds.

The use of massive radiation is very new, in fact newer than atomic energy itself. The development is therefore in its infancy, but I believe that the use of radiation may be of very great importance, and engineers of future atomic power reactors may be well advised to think about the practical aspects of using some of the immense amount of gamma radiation which, at present, is locked up idle in these plants.

I feel somewhat diffident in speaking about the application of radio-isotopes to industry in the presence of Dr. Libby, who has given us so many excellent lectures on this subject. However I cannot miss the opportunity of quoting his estimate that United States industry and agriculture is already saving $500 million a year by the use of radio-isotopes—at a cost to the U.S. Government of about $3 million. This is a remarkable example of the effects of research. However, still greater advantages are predicted for the future, and Dr. Libby estimates that the saving will rise to $5,000 million a year by 1960.

An interesting example mentioned by him is the use of radio-isotopes to facilitate oil well flow. This application alone is saving $180 million a year to the oil industry in the U.S.A. Dr. Libby also sees a great extension of process control by labelling with carbon-14 important components such as octane going into an oil refinery. This will be done with very low levels of activity, since the initial C-14 content is very nearly zero.

Lastly I might mention the important contribution which radio-isotopes, produced in large quantities for use in weapon trials, are making to studies of the circulation in the atmosphere—particularly the North/South mixing—and also to oceanography.

The potentialities of our newly won access to the inexhaustible energy of atomic nuclei are enormous. It could be used to destroy our whole civilization, but if we justify our status as *homo sapiens* and manage to avoid this catastrophe, it cannot fail in the long run to provide enormous benefit to mankind.

THE ECONOMIC ASPECTS OF RADIO-ISOTOPE UTILIZATION

by
W. F. LIBBY

Dr. Libby is a Commissioner of the United States Atomic Energy Commission (AEC) and Professor of Chemistry at the Institute of Nuclear Studies of the University of Chicago.

In the United States of America, radio-isotopes have proved to be one of the two most important peaceful dividends from atomic energy, and they have virtually become an everyday part of our industrial life. There are good reasons to believe that radio-isotopes have attracted perhaps less attention that they really deserve. I would like to try to correct this situation and hope that you will help me.

In 1953, it was estimated by the AEC that radio-isotopes were saving American industry about $100 million per year, and it was predicted that the saving might reach ten times that amount within the next decade. A recent careful review, in November 1956, based on interviews with some of the many industries using radio-isotopes, indicated that the saving had increased to between $295 and $485 million per year, with a mean value of $390 million per year. A more recent check in July 1957 indicates a new total of $406 million per year.

Now there is ample reason to believe that this saving will continue to grow. First, the known applications of radio-isotope techniques have by no means saturated the market. It is estimated, for example, that the market for radio-isotope thickness gauges is less than 10 per cent saturated. Secondly, the application of low-level radio-isotope tracer techniques to process control and to everyday medicine is just emerging from the experimental stage. On bulk products, such as petroleum, sorting of shale from coal, etc., a net saving of a penny or two per ton of the product could rapidly mount to several millions of dollars per year.

In arriving at these estimated savings, which will be discussed in more detail below, the co-operation of many American manufacturers was obtained. While understandably reluctant to reveal trade secrets, these companies were for the most part generous in furnishing specific information to the Commission regarding savings in certain applications. Some of the reluctance in supplying detailed information stemmed from an unwillingness to inform competitors of the degree of success attained in the application of radio-isotopes. It is nevertheless possible to present data in terms of totals or averages, together with a few specific examples which can be utilized without revealing the company data frequently given to our surveyors in confidence.

SAVINGS DEFINED

Direct savings are sometimes defined as the difference in the cost of doing the same operation by two different methods or by the substitution of one material for another, after taking into account in each case the cost of any necessary instruments, equipment, etc., and of manpower. One example would be the substitution of a pellet of radio-active cobalt-60 for an X-ray machine in detecting flaws in castings or welds. Such direct savings can usually be readily ascertained and understood.

The successful use of a new method or technique may also result in indirect savings of considerable magnitude in terms of better process control, fewer rejections, or perhaps savings through the use of cheaper raw or intermediate materials. One example of the indirect savings made possible through better process control is provided by the manufacture of rubber tyres, in which each strand of fabric in the cord is coated with rubber. There is a certain minimum quantity of rubber which is necessary to meet a first-line performance specification in the tyre; however, the use of more rubber than this minimum does not result in a better tyre, but simply in a waste of rubber. Quality control is therefore necessary. In one of the manufacturing plants of a maker of tyres, the former method of quality control was to send samples of the coated cord to the laboratory for analysis of the rubber content. The analysis took considerable time, and it was found that the quantity of rubber on the cord varied considerably, because the machine could not be automatically controlled. The company installed a radiostrontium-90 thickness gauge which almost instantaneously gave values for the amount of rubber on the cord, and made possible automatic control of the coating process. This had two results; first, there was a large reduction in the variability of the coating; and second, this variability being lowered, it was possible, in turn, to reduce the total quantity of rubber used, because the machine no longer had to be set as high as previously to ensure that the necessary minimum amount of rubber was put on the cord.

The use of a strontium-90 radio-isotope thickness gauge not only made for a more uniform product, but reduced the needless excess of rubber. The quantity of rubber saved was over $75,000 for one gauge. It seems proper to credit such savings to the use of radio-isotopes. There are many such examples, and a radio-isotope thickness gauge generally pays for itself within a year or less. Such savings may be passed on to the general public in the form of lower prices; or they may be retained by the company to enhance its profit potential, or to pay in part for non-profitable items manufactured by the same company.

Intangible savings may also result from the production of a superior product which has a longer life. In some cases, radio-isotopes permit information to be obtained which could not be derived in any other way, and this

information may have a cash value further down the line. The indirect savings are difficult to assess, because radio-isotopes are seldom used alone but rather as part of a device or of a test procedure. For example, a radio-isotope thickness gauge such as is used for measuring and controlling the thickness of sheet steel may save over $100,000 worth of steel per year per gauge because of fewer rejects. The gauge plus the electronics may cost $30,000 to $50,000 installed, including the servo-mechanisms for automatic control; yet it may contain only $25 worth of strontium-90. It is obviously unfair to credit the entire savings to the radio-isotope and to neglect the engineering cost of developing the gauge.

Again, having established a 'reasonable value' for the saving through the use of radio-isotope techniques, for how many years can one expect to credit a saving to this technique; and when does it simply become 'standard operating procedure'? At first thought, one might feel that the saving should continue to be credited as long as the method is in use or until it is supplanted by a better one; this, too, can lead to illogical conclusions. Should a screwdriver, for example, because it permits the assembly of electronic equipment, properly be credited with the extra productivity created through the use of the telephone?

For the purpose of this paper, we define a saving as the sum of the direct plus the indirect saving, less the selling price and installation charge for the device containing the radio-isotope. This definition is not completely rigorous in that it ignores the research and development costs of producing the device, but it is a fairly good first approximation when one considers, for example, that the research and development costs of an isotope thickness gauge are divided among the more than 3,000 gauges now in use. Similarly, the maintenance and depreciation costs of most devices are quite low and are negligible compared to the saving as defined above.

It should also be noted that many devices, in particular thickness gauges, generally pay for themselves within the first year, and the usual problems of long-term amortization of capital investment, which in itself is small, do not apply.

THE ECONOMICS OF ISOTOPE UTILIZATION

Figure 1 illustrates the cumulative growth of radio-isotope users since 1946, and depicts separately the industrial and the non-industrial users, most of the latter being in the medical field. The growth appears to be almost linear for the last four and a half years, and the industrial users now account for 41 per cent of the total.

Over the years, we have noticed a certain trend as regards the quantity of radio-isotopes purchased per user. During the period 1946-49, most of the

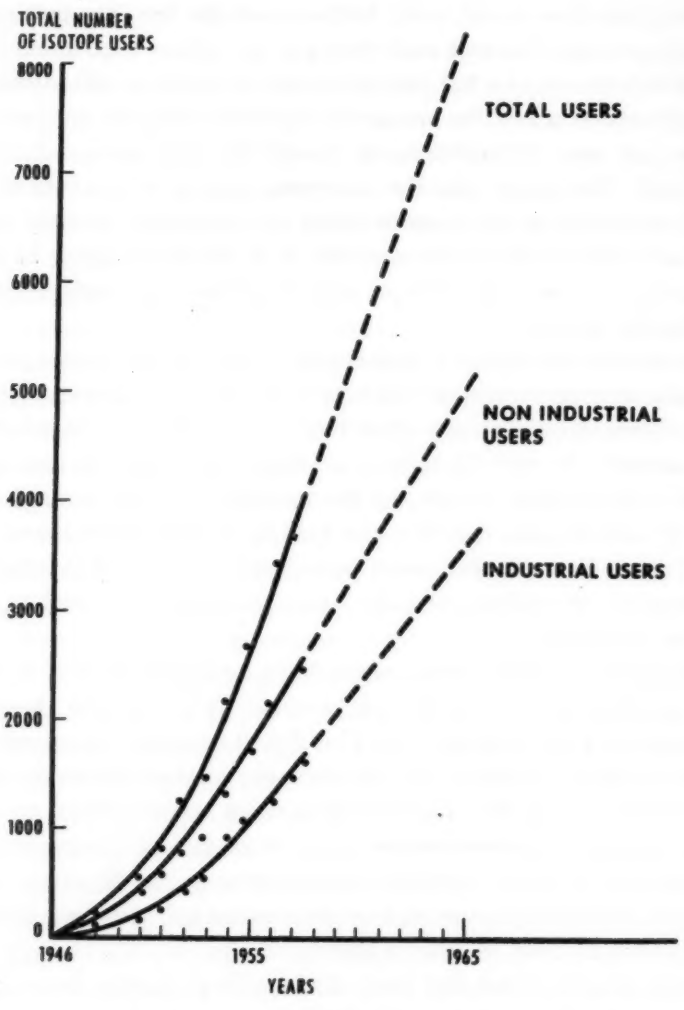

Fig. 1. Number of isotope users (cumulative since 1946).

industrial users were research laboratories investigating tracer applications —for example, the mechanism of reactions such as cracking, etc. The quantities of radio-isotopes used were of the order of microcuries or millicuries. This use is still an important part of the total isotope programme, but in addition, industrial concerns have begun to install large sources of radio-isotopes, up to tens of thousands of curies, to study the effects of nuclear radiation on the promotion of chemical reactions such as the polymerization of the components in the last stage of manufacture of plastics, pasteurization of foods, and enhancing catalytic effects in petroleum cracking. Many companies have increased their total use of radio-isotopes from the original few millicuries to as much as 65,000 curies. This represents an increase by a factor of some 10 million. In the non-industrial field—mostly medical ap-

plications—many of the institutions initially used a few millicuries of radio-iodine or radiophosphorous for diagnostic or therapeutic purposes. This use still continues, but there are many medical institutions now installing multi-kilocuries teletherapy sources of cobalt-60.

Indeed, one manifestation of this trend is the beginning of a new kind of industry in which private processing plants obtain from the AEC a large quantity of a radio-isotope, such as cobalt-60 for example; they then put it in small quantities into capsules which they sell to several hundred industrial organizations.

By 1 August 1957, the U.S. Atomic Energy Commission had issued licences to possess and use radio-isotopes to 4,182 organizations as follows : hospital and private physicians, 1,754; industrial concerns, 1,667; colleges and universities, 265; federal and State laboratories, 370; foundations and institutions, 70; others, 56.

It is interesting to observe that very few companies discontinue the use of radio-isotopes. In fact, less than 2 per cent of the number of users do so, and in most cases they have merely changed over to using the superior facilities of a consulting laboratory, instead of doing the work themselves.

An estimate of annual savings as previously defined was made in 1953. It was based on discussions with some of the major industrial users of radio-isotopes. A figure of $100 million ($\pm$ 50 per cent) per year was obtained. This figure attracted considerable attention because, for the first time, it brought to the notice of the public the fact that what was a laboratory curiosity only a few years ago, now had a business potential.

In September 1956 a more thorough survey was made by Mr. Oscar M. Bizzel of the AEC staff, based on personal visits to approximately 40 of the largest industrial firms either manufacturing or using radio-isotope products, and on supplementary information from 100 other institutions. As mentioned previously, this information was obtained through the co-operation of the manufacturers, and some of the details were obtained on a confidential basis. The confidential nature of this information has been respected.

'Probable low' and 'probable high' savings were estimated for a number of industrial applications of radio-isotopes. Annual savings to industrial firms in this country, as of July 1957, were estimated at a probable low of $312 million, and a probable high of $500 million. The average of these two figures is $406 million ($\pm$ $100 million) per year.

The table below gives a detailed itemization of the estimated rate of saving from isotopes. It is clear that U.S. industry alone is probably saving about $500 million annually at the present time.

Estimated rate of industrial savings, July 1957

	Annual savings in millions of dollars	
	Probable low	*Probable high*
Cigarette density gauges	42.7	57.0
Metal thickness gauges	18.5	27.8
Rubber and tyre fabric thickness gauges	8.0	20.3
Plastic and adhesive thickness gauges	2.0	6.1
Paper and allied products thickness gauges	23.1	24.9
Other thickness gauges	2.3	6.9
Gauges such as liquid level, moisture, H-C ratio, snow, etc.	2.5	7.6
Radiographic testing	28.7	64.6
Oil well logging	16.0	24.0
Oil well stimulation	120.0	180.0
Pipeline oil flow	0.5	0.7
Petroleum refining	5.3	10.1
Other applied industrial tracing	12.5	25.0
Tool wear studies	0.8	1.2
Piston ring and similar wear studies	12.0	18.0
Corrosion studies	3.0	4.6
Other industrial research	12.0	18.0
Luminescent sources	1.7	2.7
Miscellaneous industrial applications	0.5	0.8
TOTAL	312.1	500.3
Average :	406.2 (± 100)	

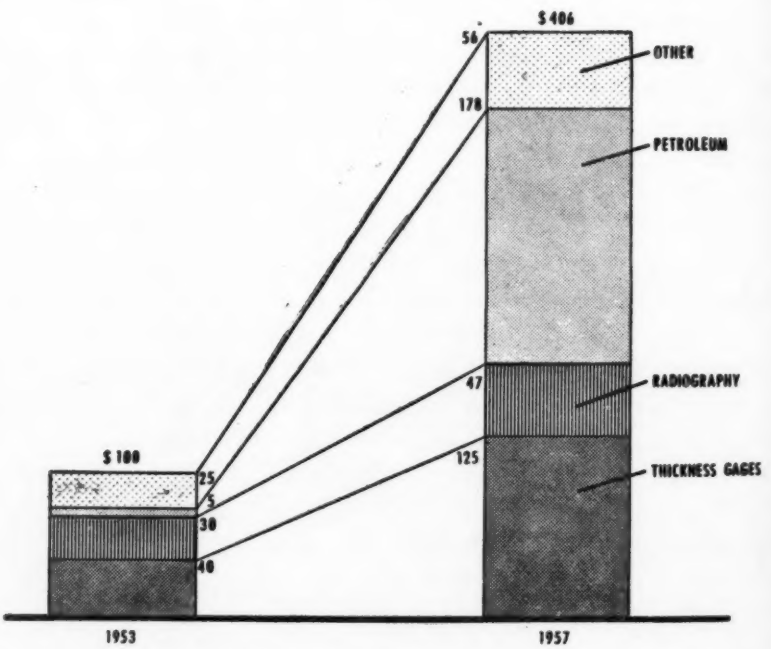

Fig. 2. Comparison of estimated savings in 1953 and 1957.

A comparison of the estimated savings in 1953 and 1957 is shown in Figure 2. The rise of the saving in the field of petroleum applications is encouraging, and more will be said of this later. The 1957 figure of \$406 $\pm$ \$100 million per year is felt to represent as careful an estimate of the savings as is possible at present.

Figure 3 gives the estimated savings in the course of the last four years. The curve slopes steeply upward, and an extrapolation suggests that within the next decade the savings will be severalfold those of today.

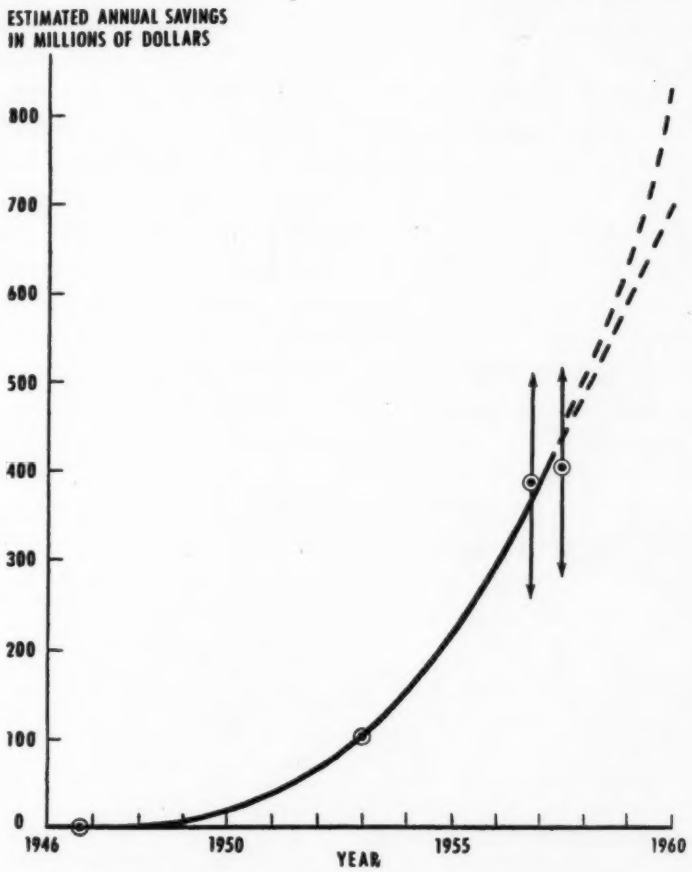

Fig. 3. Estimated annual savings plotted against time.

TRENDS IN SAVINGS

It is difficult to know how to extrapolate such a curve which, in the first place, is based on only four points (including the origin), and secondly, has a slope which is increasing so rapidly.

There are a number of reasons why the straightforward extrapolation in

the graph may actually err on the low side. The 1,667 industrial firms using radio-isotopes in July 1957 represent only 0.6 per cent of the 288,000 manufacturing establishments in the U.S.A., and it is reasonable to expect that the figure of 0.6 per cent will increase at least severalfold. This would mean a corresponding increase in the volume of isotopes used per year, and a consequent increase in savings.

It may be pointed out in this connexion that 250 of the largest 500 manufacturing establishments in the U.S.A. are now using radio-isotopes in some form. These manufacturers, according to *Fortune* magazine, sold 51 per cent of all the goods and services in the U.S.A. in 1956. It is reasonable to expect that the remainder will soon be using radio-isotopes, and that the industrial economies effected might therefore reach $5,000 million per year in four or five years. More important, however, is the fact that the savings per user are likely to increase faster than the number of users. This is because an industrial user may begin with one thickness gauge, and in time equip each of several production lines in the company's plants with thickness gauges. One company operates more than 100 thickness gauges in its various plants.

Undoubtedly, a lowering of the selling prices of radio-isotopes would broaden their market and widen their use in industry. The production of radio-isotopes by the Commission is on a small scale compared to its other operations, and the unit costs are still fairly high. If, however, one were to expand the production of isotopes a thousandfold or ten thousandfold, and were to apply to them the same research and development efforts that have gone, for example, into the reprocessing of production reactor fuel elements, the price of radio-isotopes would drop sharply.

On this basis, the lowest—or 'rock-bottom'—costs that might be obtained in producing some of the isotopes would be as follows.

Rock-bottom prices of isotopes[1]

Isotope	*Half-life*	*Rock-bottom cost (per curie)*	*Present selling price (per curie)*
Non-transmuted neutron-produced isotopes		$	$
Co-60	5.3 years	0.06	2-5
Chemically-transmuted neutron-produced isotopes			
H-3 or T	12.26 years	0.25	2
C-14	5,600 years	100	22,000
S-35	87 days	0.005	2,000
Fission products			
I-131	8 days	0.0004	400
Cs-137	33 years	0.30	10

1. Based on approximately $7 per milligramme of neutrons, of which $4 is production of material and $3 is for chemical separation of the isotopes.

The rock-bottom values given in the table above are based on published prices for plutonium at $30 per gramme and on the formula:

$$\text{cost in \$ per curie} = 3.7 \times 10^{-8}\ T_{\frac{1}{2}}$$

where $T_{\frac{1}{2}}$ is the mean half-life of the radio-isotope in minutes. The formula provides a ready method for calculating rock-bottom costs, and serves to indicate which isotopes are capable of large-scale industrial applications from the point of view of cost. It indicates that the lower the mean half-life, the lower the cost, but it is not intended to be applied to isotopes of very short half-life, because in such cases the decay factor and the transport problem—if involved—would raise the real cost of the isotope to the user.

It is clear from the table that, in nearly every case except tritium, the present selling prices far exceed the 'rock-bottom' price calculated on the assumptions described. The Commission operates on the basis of over-all recovery of costs in the isotopes programme which allows the large-volume isotopes to carry the cost for the low-volume isotopes; thus the true cost of the individual isotope is not reflected in each case. Another factor is, of course, that the volume of isotope sales is extremely small compared to the volume of reactor production on which I have based these figures. In other words, the cost of producing radio-isotopes is in something like an inverse ratio to the volume of sales, and will drop very steeply as the result of an expanded radio-isotope programme. In many instances, the potential uses of isotopes are so large that the prices listed above may be considered as possibly practical and realistic; on the other hand, it might be wise to rule out potential uses where the costs will always be prohibitive.

On 1 August 1957 the U.S. Atomic Energy Commission reduced prices for radio-active cobalt—by approximately half for large quantities. These new prices are expected to encourage more widespread use.

POTENTIAL MARKETS FOR NEW ISOTOPE USES

We believe that there are markets as yet untapped which, when exploited, should increase the savings or economies markedly. In many cases the new uses will be applicable to process control.

From this and similar considerations, I predict that during the next five years the isotope uses in the U.S.A. will increase at least tenfold, so that the savings by 1962 should amount to $5,000 million annually. The rate of application is determined by the speed with which we learn of possibilities and not by technical barriers; we can expect that normal educational methods will spread the news—and that is what I am doing here tonight. You can help me by telling everyone that isotopes are wonderful, that they can do many, many useful jobs, and that they are safe and cheap. Tell your investors that money can be made not only by using them, but also by supplying them

and the instruments for their use. Isotopes are here now, and are ready for immediate application; their use can repay the costs of the expensive atomic power programmes.

Let us now consider where we are going to get the main part of the additional $4,500 million annual saving from isotopes. We are going to get it by greatly expanding the uses as described above, and by developing the tremendous possible new applications. For example, the organic chemical industries, including the oil industry, do not at present make any important use of either radio-active carbon or radio-active hydrogen, the two most important elements with which they work in their normal manufacturing operations. It is obvious that applications of extreme importance to every organic chemical industry exist by way of controlling production operations through judicious labelling at safe low levels of the material being processed. For example, suppose we wished to label a certain constituent of crude oil, say octane, going to an oil refinery. Then, at the rock-bottom prices, the whole of the oil used in the U.S.A. could be raised to the level of radio-activity normally present as radio-carbon in living matter through the action of cosmic rays for something like $130,000 per year. At this level, plant control could be accomplished, because the natural radio-carbon content is very nearly zero owing to the great age of petroleum—the cosmic ray radio-carbon having long since decayed out of the organic matter which constitutes the crude oil. Now the rock-bottom prices may be somewhat optimistic, but even a tenfold higher price is still tolerable in this important application. Similarly, we can expect that tritium labelling of the incoming crude oil might be useful for operations not involving bond rupture (such as distillation), and would also result in considerable savings.

A great potential use lies in placing short-lived isotopes in the intermediate product itself, and in using the radiation from these isotopes to control the process. In many cases the short-lived isotopes may be preferable to the longer-lived ones such as C-14 and tritium, because the product as finally produced is completely non-radio-active—though the amounts of C-14 and tritium needed for labelling are in any case completely safe; the sensitiveness of the instruments makes the dilute concentrations practical.

An extremely important potential development in the use of isotopes lies in radio-active drugs and medicinals as well as organic chemicals. In many instances these substances must be grown rather than synthesized in the laboratory. Some six or seven years ago, an isotope farm was established at the Argonne National Laboratory of the AEC near Chicago, for the purpose of supplying the raw materials needed for these applications. As a result, we now have a national treasure in a barnful of radio-active plants of many different types, all stored and ready for the chemical extraction and separation needed to produce the desired medicinals and chemicals.

One other isotope farm has been established—at the Medical College of

Virginia in Richmond—with the aid of the American Tobacco Company. A paper describing this installation was given by Dr. P. S. Larson and Mr. E. Harlow at this conference. It seems likely that isotopic biosynthesis on an appreciable scale—as good a definition as any of isotope farming—will grow in importance as part of the expansion and development of the isotope programme.

Another ancillary development of the isotopic, organic-chemical complex is the production of desired labelled organic compounds by direct exposure of organic materials to neutrons in the piles; the labelled products are thus obtained directly by virtue of the recoil energy of the radio-carbon or tritium atoms produced by the neutrons. This method is known as hot-atom chemistry. At the recent national meeting of the American Chemical Society in Miami a symposium was held on this subject.

Lastly, direct synthesis by standard organic chemical techniques can, of course, be used. This has been carried on for some years on a certain scale, and will probably increase in importance.

It has already been amply demonstrated that the isotope farm products are of great value in biochemical and medical research. There is another possibility, however, that I wish to mention—namely, that these products may have great value in ordinary medical practice, and doctors may come to use radio-active pills in normal medical practice for diagnostic purposes. It would seem not unlikely that the feeding of a radio-active sugar pill to a patient suspected of having an abnormality in his sugar metabolism could furnish an easy and particularly illuminating way of testing that metabolism. Perhaps a patient would be asked to blow up a balloon so that carbon dioxide in his breath, at various times after taking the pill, could be sampled for radio-active carbon dioxide; it might also be illuminating to examine the radio-active sugar content of the blood and urine at various times. In this way, one might develop a method of testing for abnormalities in the sugar metabolic mechanism which would be far more sensitive and reliable, or in other ways more desirable, than present techniques. Research quantities of radio-active sugars labelled in specific positions have already been prepared at the National Bureau of Standards, and the Argonne Isotope Farm of course has them labelled at random in great quantities. It seems likely that in the future isotope farming may be carried on to supply such routine diagnostic needs, probably through the regular pharmaceutical houses.

The plant products from the isotope farm have been used in many ways, mainly because it has been possible to detect and isolate natural products from those plants in concentrations which are beyond the limit of detection by ordinary chemical essay methods. Among the more important of the labelled compounds isolated are digitoxin, morphine, nicotine, amino acids, proteins, and vitamins, as well, of course, as the more abundant materials. In the case of many of these compounds, this is the only way in which they

can be obtained at the present time in radio-active form for use in tracer research or diagnostic purposes, their synthesis being beyond the skill of the organic chemist.

To give an example of uses so far, the digitoxin so produced has been used to study the problem of placental transfer of this important material from a pregnant mother to the foetus. Again, the use of radio-active labelled morphine has made possible the study of the effect of morphine antagonists on the distribution and excretion of morphine in mice. Numerous other similar applications have been made in medical research.

We may conclude by saying that a golden future lies ahead of us in the field of industrial and medical uses of isotopes and radiation. Just as today no research man works without isotopes, so tomorrow no manufacturer or farmer will think of doing without them, no doctor will go without radio-active pills and Geiger counters in his bag; no school will neglect the teaching of radio-activity, and with universal knowledge the age of isotopes will be in full swing.

RADIATION EXPOSURE AND THE USE OF RADIO-ISOTOPES

by

LAURISTON S. TAYLOR

Dr. Taylor is Chief of the Atomic and Radition Physics Division at the U.S. National Bureau of Standards. He is also Chairman of the International Commission on Radiological Units and Measurements, and a member of the International Commission on Radiological Protection. The full title of this lecture was: 'The Effect of the New Lower Permissible Radiation Exposure Levels on the Use of Radioactive Isotopes'.

The lecture this evening will be based mainly on what are believed to be the views of the International Commission on Radiological Protection (ICRP), the International Commission on Radiological Units and Measurements (ICRU), and the U.S. National Committee on Radiation Protection and Measurements. The main purpose of the discussions will be to explain the background of the problem of protection against the harmful effects of radiation. With an understanding of this it should be easier to apply the protection measures prescribed by various responsible bodies for the solution of specific problems. Protection cannot be adequately supplied by rule alone—any rules should be regarded mainly as guides, and should be freely supplemented by good judgement, common sense and a full understanding of the end objectives.

Most radiation workers are aware, at least in a general way, of the existence of so-called 'maximum permissible limits of radiation dose'; what is not so certain is their understanding that these levels are to be regarded as maxima, and not as levels which should be applied without further question to the whole population, or even the much smaller group of radiation workers.

For the last thirty years the International Commission and related national bodies have, without exception, emphasized the need for working as far below the maximum as circumstances permit. Part of the reasoning behind this emphasis has been the strong feeling, based upon very limited evidence, that it might be necessary to establish lower permissible levels when the fraction of the population exposed becomes substantially larger. That time is now approaching. Another part of the reasoning has been based upon sheer prudence, with the knowledge that, aside from medical applications, no radiation is good for man.

The possibility of the lowering of the permissible exposure levels has been mentioned. Such lowerings have occurred, in several major steps, since the first quantitative limits were established by the ICRP in 1934. The reasons

for this have been various and, except for the most recent change, will not be discussed in any detail. Suffice it to say that the principal factors have been, first, an improved knowledge of radiation effects on the human system, and second, the engineering developments that have made it possible to confine much better the undesired radiation, in spite of the much greater quantities being used.

RADIATION RISK—A MATTER OF PHILOSOPHY

It may perhaps sound startling to contend that the establishment of permissible levels of radiation exposure is not basically a scientific problem. Indeed, it is more a matter of philosophy, of morality, and of sheer wisdom. True, the basic knowledge used in establishing radiation levels is derived from scientific sources, and by and large the use and application of this knowledge must be the task of scientists drawn from many fields of endeavour. Also, the achievement of the protection goals is purely a matter of science and engineering.

But before a maximum permissible dose of radiation can be set for man, there must be an unequivocal answer to one question: 'What amount of radiation may man receive in either chronic or acute exposure without any harm to himself or his progeny?' At present the only answer to this question is: 'None'. There is today little or no direct positive proof that there does or does not exist some level of exposure below which harm will not result. It was recognition of this lack of proof that led the ICRP many years ago to discard the term 'tolerance dose', which implied that there was some degree of irradiation that was wholly without harm. In its place is used the term 'permissible dose', which, while not completely unobjectionable, does not carry the connotation of absolute safety.

There are, then, two factors that remove radiation protection from the field of science to the field of philosophy: (a) lack of a clear and scientifically unobjectionable answer to the question posed above, and (b) the consequent necessity for assuming that any amount of radiation, no matter how small, is harmful.

In spite of the lack of direct knowledge of radiation effects on himself, man has recognized, and become accustomed to, the advantages that radiation offers him, both as regards his health and his material well-being. These advantages will not be given up lightly—probably will not be given up at all.

The problem centres about a philosophy to which we are all well accustomed; it may be called a 'philosophy of risk'. In nearly every phase of ordinary life we accept, knowingly if we think about it at all, risks of commission that could cost us our lives. These risks are accepted in the belief that the possibility of gain offsets the chance of loss. One naturally makes

every attempt to reduce the element of risk to a minimum, but in rare instances only can it be reduced to zero. To attain zero risk, it is almost certain that life itself would have to be given up. We are thus continually in a situation of having to effect a suitable compromise between risk and gain. The effectiveness with which we can weigh conditions and arrive at a compromise depends upon our knowledge of both items—risk on the one hand, and gain on the other.

Let us mention some examples of the risks that we commonly accept: virtually any mode of transportation from boat or bicycle to the aeroplane—but without these life today would be very different indeed; smoking, a luxury that we could well do without—except that we would probably find some other relaxing habit that would be just as dangerous; many forms of medication to which there are dangerous individual idiosyncrasies or allergies.

In essence, radiation risk is no different from these, except for the very important aspect of its probable mutagenic effect that will continue for generations. But there are accepted risks of other nature which may also have some small mutagenic aspect.

With all our lack of direct knowledge of the biological effects of radiation, it is still fairly clear that radiation offers direct advantages to our health or material well-being. As regards health, it is certain that radiation techniques have made a most important contribution to our greatly increased life expectancy. But so also have anti-biotics, drugs, surgery and so on, and it is probably impossible to evaluate the exact contribution of each. In industry, radiation as an examining tool is used to detect the imperfections of parts, the failure of which might cost many lives. In research, radiation has offered whole new avenues of approach to the solution of problems essential to our growth of knowledge. The advent of nuclear power may have come just in time to alleviate critical power shortages in some countries, and create new sources of power in countries which previously had none at all. But each of these uses has its own quota of risk to someone. Are they therefore to be given up? I think not, but there should be a continuing struggle to push the risk to still lower levels.

In comparison with the gains, the risks from radiation use are not very clear and are particularly difficult to define on a cause and effect basis. Except in relatively rare instances, there is almost no knowledge relating death, shortening of life expectancy, or genetic abnormalities in man, to a specific dose or a particular radiation exposure. It is unfortunate, for analytical purposes, that practically any radiation effect can also be caused by other means, known or unknown. Most radiation effects can be detected only by statistical studies on relatively large population samples. To many persons grown accustomed to risky living, death statistics have little interest until they themselves figure in them—and then of course it is too late. Who worries

because he carries in his pocket two personal death warrants—a packet of cigarettes and an automobile driving licence? This is mentioned, not to allay any fears, but to emphasize the complexity of the problem and its relationship to good judgement and wisdom.

SOMATIC AND GENETIC DAMAGE

Let us consider very briefly the two main types of radiation damage to man—somatic and genetic. Until about ten years ago, the main emphasis was given to somatic damage—that is, damage to the body cells of the individual exposed. The basic protection criterion had been to set the exposure levels sufficiently low, so that no detectable damage to the individual would result. The possibility of genetic damage was not overlooked, but too little was known about it to permit of its sensible evaluation. Particularly in the light of present knowledge, there is a very real question as to what constitutes 'detectable damage'. Certainly a skin lesion is detectable, but a similar lesion within the body might pass undetected forever. If undetected damage exists and the individual dies from seemingly normal causes, who is to say whether or not that damage may have contributed in some obscure way to that death? In fact there is increasing evidence based on animal experiments that there is such a relationship.

Up to now there has been little, if any, acceptable evidence that chronic exposure to radiation at the levels prescribed since 1934 has resulted in definable or detectable damage. It would appear, but no more than appear, that the permissible exposure levels have always been low enough from the point of view of specific somatic damage.

The possibility of genetic damage has been known to us for some twenty-five years but, as already mentioned, our knowledge was largely qualitative until a few years ago. Even now most of it is based on animal experiments—human experience is extremely limited; but the burst of effort in studying the genetic effects of radiation over the past ten to fifteen years has substantially enhanced our knowledge of the subject. Particularly within the past few years the emphasis on genetic effects has increased enormously—some fear it to be out of proportion to the importance of other radiation effects.

The treatment of the genetic problem is one requiring the utmost wisdom and morality. For, whatever the effect of radiation on our genetic status may be, its principal impact will not be upon the generation of individuals exposed. Rather will it be distributed over future generations, up to perhaps fifty in number. Whether the effects on these future generations are to be good or bad—and on the average the prediction is bad—the control of that future lies in our hands. The dilemma is complicated by the fact that there may never be a means by which cause and effect can be clearly established.

Deleterious mutations due to irradiation of persons at presently accepted levels may only be a fifth of those resulting from all causes—the other four-fifths may be spontaneous, or of unknown cause. To what degree are we to be held responsible for our known contribution to this legacy for the future? What is our moral obligation in this regard? The answer is clear: to be morally right, ignorant though we are. We must do all in our power to reduce genetic damage to a minimum commensurate with our continued use of radiation as an immeasurably valuable servant to man. A workable balance between risk and reward must continually be sought—and is being sought. The recommendations of the ICRP in 1956, based on their earlier findings beginning in 1952, reflect this balance within the scope of present knowledge and technical capabilities.

The geneticist contends that zero radiation exposure to man, apart from natural background radiation, would be the ideal goal, and though as yet unproven, he may well be right. This of course, means the complete discontinuance of all radiation use—an unacceptable alternative. The problem thus confronting us is to determine or, perhaps better, to decide how much above zero we can operate. The levels at present recommended by the ICRP reflect the best decision on this delicate question that can be reached today. Tomorrow it may be possible to make a wiser decision.

LOWER EXPOSURE LEVELS

The newly proposed levels of radiation exposure represent a compromise between what we want to accomplish and what we can accomplish while still retaining the necessary uses of radiation. They will introduce temporary hardship to operators in some fields, but on the whole will not seriously interfere with major or worthwhile uses of radiation. They will involve some re-education in the technological world, and some new education for the public. The fact that we can lower our permissible exposure levels by a factor of three below those of ten years ago is a tribute to the world's radiation industry. Its technological advances over that period have been one of the most important factors in lowering these levels.

Let us consider for a few moments the permissible exposure levels over the past three decades (see Table 1). The latest level recommended by the ICRP in 1956 averages about 5 rems per year[1] for occupational exposure. From 1950 to 1956 the average was about 15 rems per year; from 1934 to 1950 the average was 60 rems per year (in the U.S.A. the National Committee on Radiation Protection (NCRP) recommended 30 rems per year in

1. The rem is a unit of biological radiation dose, and applies to all kinds of radiation, including neutrons. It is the product of a measured absorbed dose and a factor called the 'relative biological effectiveness'. For X-rays and gamma rays 1 rem is essentially equal to 1 roentgen.

1935); prior to 1934 the levels were of the order of 100 rems per year. Yet at none of these levels has there ever been any positive evidence of damage to the individual. In the main, these successive lowerings represent improved compromises between goal-zero and capability. Again, capability has been made possible by technological advances.

Table 1. Permissible occupational exposure levels

	Rems per year
ICRP (April 1956)	5
ICRP (1950 to 1956) at 0.3 rem per week	15
NCRP (1935 to 1948) at 0.1 rem per day	30
ICRP (1934 to 1950) at 0.2 rem per day	60
Prior to 1934	100

Of course, the objectivity of our damage criteria is marred by the possibility of a shortened average life span which, if real, must be classed as damage. Recent studies of the life shortening of radiologists are now considered by some to be inconclusive in the quantitative sense, but it is generally believed that there must be some such effect on man. The estimates vary so enormously as to cast doubt on all of them.

In all the considerations by the ICRP there has been no assumption of any kind of threshold level below which specific or general radiation damage does not occur; in the absence of any positive knowledge, this seemed the only acceptable conclusion. This is not to imply that there may not be some specific threshold, though at the moment the possibility of its existence seems remote. Statistical data such as those recently obtained for leukemia incidence, while not completely free from objection, points to the conclusion that there is no threshold.

Thus all indications seem to point to the fact that present and future solutions of the radiation protection problem will have to be based on a risk philosophy; they will have to be compromise solutions, and cannot be solved on the basis of scientific evidence alone.

At this point one may well ask why so much emphasis has been placed on a discussion of the background philosophy of radiation protection. The purpose has been to emphasize the fact that protection against the harmful effects of radiation is not a straightforward problem for which there is a simple black or white solution. A degree of protection can be had—the exact degree depends upon each of us who uses radiation. Rules provide some basic guidance as to limits which may be regarded as acceptable today, but should never be considered as ideal. Continuous efforts must be applied towards working with lower levels—as low as possible commensurate with the task. The extent to which these efforts are successful may very well affect the whole future use of radio-active isotopes and nuclear power.

Let us now examine the new permissible radiation exposure levels as recommended by the ICRP in April 1956. These new recommendations have not been made capriciously, but have resulted from studies begun in 1952, at which time the ICRP had arrived at essentially the same conclusions as those reached four years later. However, in 1952 they felt that existing data were inadequate and the problem insufficiently urgent to warrant hasty action. While our knowledge has not increased enormously since then, the urgency has increased to some extent because of the more widespread use of radioactive materials, and because of the public concern over fall-out and the development of nuclear power.

The new levels have been dictated mainly by reasons of genetic damage, but it must now be recognized that somatic damage possibilities are assuming equivalent importance. As already mentioned, the direct evidence of genetic damage to man is almost totally lacking, and that of somatic damage is at best very scant.

In terms deliberately general, the ICRP has made two principal recommendations on the maximum permissible dose: (a) for the population as a whole, the average *per capita* dose should not exceed 10 rems from conception up to age 30 (and by inference one-third of this amount per decade thereafter); (b) for radiation workers, the individual occupational dose should not exceed 50 rems up to age 30 (and again this same amount per decade thereafter). It is obvious that these need further interpretation. For that purpose the most recent interpretation made by the National Committee on Radiation Protection in the United States will be discussed. Interpretations by other countries may differ.

Dealing only with the problem of occupational exposure, an allowance of 50 rems up to age 30 implies an average of about 5 rems per year, assuming ten working years. For fairly obvious reasons, it is impractical to integrate a person's dose over a period as long as ten years. Since genetic damage was a primary consideration in setting the new levels, it is important to limit the gonadal dose as much as possible in the years during which most children are conceived. Thus is would be desirable to delay the exposure as long as possible—at worst to distribute it more or less uniformly at the rate of 5 rems per year.

LEGAL DIFFICULTIES

This solution, however, is not without its difficulties, since our legal machinery is accustomed to dealing with the individual and not with averages. The difficulty in dealing with an 'average number' arises because of the fact that the safety recommendations of a few years ago are now becoming legal requirements backed up by varying degrees of enforcement or pressures.

During the twenty-five years beginning in about 1930, radiation safety the world over was based on the ICRP recommendations backed up by voluntary compliances and good sense. It must be admitted that there have been times when neither compliance nor good sense prevailed, but in the vast majority of situations they did. The tendency now is for governments to call for strict codification and the development of radiation protection regulations wherein a situation is either black or white. Here begins our trouble.

If we say an average dose of 5 rems per year, but not more than 50 rems in, say, ten years, we mean just that. There is no difference if a person is allowed to receive, say, 7 rems in one year and 3 in the next, as compared with 5 rems in each year. On the other hand, it would clearly be wrong to allow a person of age 20 to receive, say, 25 rems in each of two successive years. It would be even more wrong to deliver such doses to a person, say, of age 20.

To illustrate the difficulty, suppose we just say an average of 5 rems per year. Legally this will be interpreted as no more than 5 rems per year. Everything must be black or white, and any individual who has been so unfortunate as to have recorded against him a dose of 5.001 rems might believe he had legal grounds for redress from his employer. This is sheer nonsense, if on no other grounds than the fact that we cannot actually measure his significant dose with an error of less than $\pm$ 10-20 per cent. Yet it is difficult to evolve a law in this field where there is adequate latitude for ordinary reasonableness.

Consider the cost to plant operation if a legal limitation of 5 rems per year is put upon the individual worker. Plant management would be foolish to plan its operations in such a way that part or all of its workers would be allowed to take a dose closely approaching 5 rems per year. Experience has demonstrated that one or two people are bound to exceed this, and even though it is known that a slightly higher exposure is without harm, the employee might seek redress. Because of this fear, the plant must plan its operation so that, in general, no employee can receive more than say 40 or 50 per cent of the permissible exposure. This could be very costly and could seriously retard the atomic energy industry.

Where sufficient assurance can be provided that monitoring and recording methods are adequate, the widest latitude in the use of permissible exposure levels should be allowed. It is not known how this can be worked out legally, but it seems fairly certain that in operations of any substantial size, it would pay the employer to have adequate measuring and recording systems, and then to be allowed wide latitude in his use of the recommended permissible levels.

The main difficulty may occur with the small users of radiation sources, where there is transient employment and where the cost of monitoring equipment may be incommensurate with the cost of the operation. For such users,

permissible exposures integrated over one week, or at the most three months, would in all probability be the most feasible.

This problem may be overcome by means of a simple formula relating a total permissible accumulated dose to the age of the individual. This interpretation says that at any age of 18 or over, an individual may be allowed to accept a dose such that his total accumulation in rems will not be in excess of 5 times the number of years over 18. The age of 18 is the youngest at which a person in the U.S.A. may be employed in radiation work. This age limit may be different in other countries.

The following is the exact statement by the NCRP:

> *Accumulated dose.* The maximum permissible accumulated dose, in rems, at any age, is equal to 5 times the number of years beyond age 18, provided no annual increment exceeds 15 rems. Thus the accumulated MPD = 5 (N-18) rems, where N is the age and greater than 18. This applies to all critical organs except the skin, for which the value is double.

The interpretation given above implies that when a person starts radiation work for the first time, at some age over 18, he will be able to accept a higher dose per year provided that, firstly, it does not exceed 15 rems, and second, he does not exceed his age-prorated maximum. This means essentially that the individual has built up a reserve of permissible exposure. But such a concept, if exploited, carries certain obvious dangers. On the other hand, if every individual in an operation carries some reserve, it will unquestionably make for simpler and more economical protection procedures. The principle should, however, not be exploited to the point where persons are required to accept radiation exposure that would with reasonable care be avoidable.

The age proration principle automatically holds down the exposure at the younger ages where it is most critical. It gives leeway at the older ages where it is less critical.

This principle places somewhat of a premium upon the employment of older persons with little or no radiation exposure history, especially for tasks involving unavoidable exposure at levels above the average. However, the age-prorated maximum is overridden by the yearly maximum which should not be exceeded. While an operator may never want to avail himself of the flexibility inherent in the age proration principle, its existence offers particular advantages as well as good insurance in special circumstances.

Application of the principle is illustrated in Figure 1. The area under curve A illustrates the region within which a person's accumulated dose must be contained under the new requirements. The broken curves drawn in this area show hypothetical illustrations of how the dose principle may be applied in individual cases. The maximum by age 60 would be 210 rems.

The region below curve B shows the comparable dose limits under the provisions that have applied in the U.S.A. from 1947 to 1957. Here at age 60 the maximum would have been 630 rems.

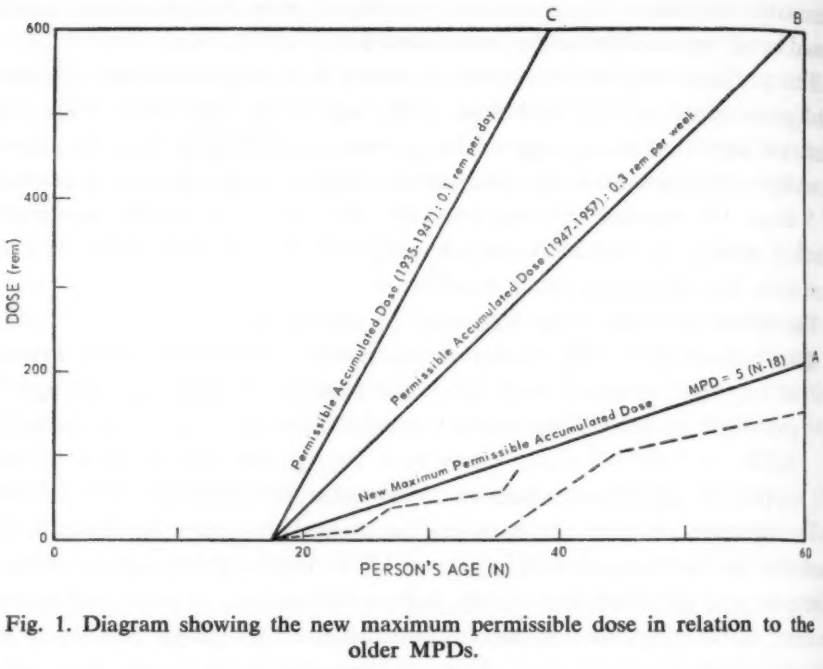

Fig. 1. Diagram showing the new maximum permissible dose in relation to the older MPDs.

The region under curve C shows the limits recommended in the U.S.A. between 1935 and 1947. The total at age 60 could have been 1,260 rems.

During about the same period—from 1934 to 1950—the maximum permissible accumulated dose as recommended by the International Commission on Radiological Protection could have been as high as 2,520 rems by age 60, or more than ten times the present new levels.

For design or planning or operational purposes, plants may wish to use average weekly, monthly or quarterly levels, and do their monitoring accordingly. Under our interpretation this will be permitted. Where it is desired to keep monitoring and recording procedures to a minimum, it would probably be wise to operate in most cases on a weekly or monthly basis anyway. The choice of procedure will depend largely upon the economics of any particular situation.

Where a person's exposure in prior employment may be unknown or undocumented, he will be presumed to have had the maximum dose permitted up to his particular age.

It might be pointed out that the levels discussed above need not be modified by the addition of one emergency exposure of 25 rems during that person's lifetime. It might also be noted that these exposure levels are not modified by any radiation exposure received for medical reasons. On the other hand, it would be prudent for the employer to take any especially large medical exposures into consideration in the assignment of an individual to radiation work.

So far, the discussions have been concerned with irradiation of major portions of the body by external sources. The data apply more specifically to the critical organs, which are the blood-forming organs of the trunk and long bones, the gonads, or the lenses of the eyes. An exception is the skin of the whole body when subjected to very soft radiation; in this case, the dose limits may be doubled. Another exception would be the hands and forearms, and feet and ankles, for all of which the levels remain unchanged at the 1950 values.

Permissible radiation levels for internal emitters have always been directly related to the external irradiation values, and this relationship will continue for occupational exposure. When the critical organ is the gonads or the whole body, the maximum permissible dose (MPD) will conform to the age-prorated limits. Correspondingly the maximum permissible concentration (MPC) in air and water will, in these cases, be one-third of the values heretofore specified for radiation workers. There is a fortunate circumstance here, in that for most radionuclides the critical organs are highly localized and are other than the gonads or whole body. For such limited critical organs, the old concentrations will still apply—subject of course to correction as our knowledge increases. It is only for some 8 or 10 radionuclides that we must consider the whole body or the gonadal dose. These would be radionuclides such as Na-22, Na-24, H-3, Cl-36, Cl-37, A-37, Br-82. It is thus clear that the new permissible dose levels will not too seriously affect our present practices with regard to most internal emitters.

PROTECTION PROBLEMS

Let us examine briefly some of the problems that will be introduced by the new protection standards. For radiation from external sources the new levels are effectively one-third of those in use up to now. This will not seriously affect the larger nuclear industries, except in relatively rare instances. Repeated warnings by the ICRP and related national bodies have indicated that future levels might have to be still lower. In any case the nuclear industry, by and large, has pioneered the development of conservative radiation practices, with the result that they have operated with a fairly large margin of safety. It has paid. While that margin of safety will be narrowed, some margin will still remain. Also, with the flexibility inherent in the age proration principle, some means will readily be found to comply with the new recommendations.

In the case of lighter industries, research and medicine, the problems may, in many instances, be more serious. In some situations, economic or structural considerations have led to practices which may have been more nearly marginal with respect to the old standards. In many instances also, it has been necessary to operate in close proximity to persons who are not classed

as radiation workers. Under the old ICRP standards, it was not permitted to expose non-radiation workers to levels greater than one-tenth of the occupational levels.

It has not been finally decided whether the non-occupational levels will be one-tenth of the new levels or remain at one-tenth of the old levels, but if we are to hold down adequately the average non-occupational dose for somatic as well as genetic reasons, it may be necessary to work to one-tenth of the new standards. Since this is only three to five times the natural background radiation at sea level, it is obvious that serious protection problems may have to be faced.

Consider, for example, the use of radio-isotopes in medicine and industry, where they are employed in telecurie therapy or radiographic examinations. Weight and mobility considerations alone dictate the lightest possible shielding container. Secondary protection afforded by walls and floors, if at present marginal, will have to be increased in thickness by about two half-value layers.[1] This can not only be costly in existing installations, but in some instances may be completely ruled out because of floor-loading considerations.

There are two other problems not within the scope of this conference. One relates to the medical use of X-rays; since many such installations are in more or less conventional buildings, it will be difficult to increase the shielding. Another problem involves high energy accelerators where two half-value layers of protective concrete might be as much as 30 centimetres.

In the isotope production and separation industry, new shielding problems may arise in the secondary establishments. In the reactor installations there are probably already adequate margins of safety, but this is less likely in areas where the materials are handled and fabricated into devices for the public.

As already mentioned, the new shielding problems in heavy nuclear industry will be slight. The standards for concentration of radio-active materials in air and water will not be changed for most elements. Problems of protection of the public will not increase greatly, mainly because most large installations are fairly well isolated.

To sum up the situation, it appears that because of the wise practices developed over the past fifteen years, we have already prepared ourselves against what might otherwise have been a severe dislocation of our budding nuclear industry. Continuance and extension of these wise policies will just as surely pay big dividends in the future. The elements of wisdom, common sense and personal good judgement are essential if the use of radio-active isotopes in the service of man is to be adequately exploited.

To give some idea of the nature of the over-all protection problem, it may

1. One half-value layer is the thickness of material required to reduce the radiation dose rate to one-half its original value.

help to show the relative contributions to man's radiation exposure from all major sources. Table 2 shows the more important contributions to man's radiation exposure up to age 30. Most of the numbers are estimates which are probably on the high rather than the low side, and are based on conditions in the U.S.A. The doses are expressed in man-rems per million of population. This is to emphasize that exposure of the population as a whole is the more critical feature.

Table 2. Radiation dose received up to age 30

	Man-rems per million population
Natural radiation	4,000,000
Medical irradiation	5,000,000
Occupational exposure	150,000
Radiation in plant environs:	
At one-tenth of new MPD	(150,000)
At one-tenth of old MPD	450,000
Fall-out	200,000
TOTAL	9,800,000
MPD	14,000,000
Balance	4,200,000

The ICRP now recommends that the average *per capita* dose for the whole population should not exceed 10 rems up to age 30. This is in addition to the natural background of about 4 rems over the same period. Thus the total permissible dose would amount to 14 million man-rems per million persons.

The dose from natural radiation acts over the full 30 years on the whole population and will contribute 4 million man-rems.

Medical irradiation is averaged over the whole population for 30 years, and in the U.S.A. might possibly be as high as 5 million man-rems.

Occupational exposure at an average of 5 rems per year acts on a third of 1 per cent of the population over a period of 12 years, up to age 30, and contributes 150,000 man-rems.

Irradiation of non-radiation workers in the environs of radiation sources might conceivably act on 1 per cent of the population for an average of 30 years, though this seems highly unlikely in the foreseeable future. At one-tenth of the new occupational levels this would contribute 150,000 man-rems. At one-tenth of the old levels the contribution would be three times as large, or 450,000 man-rems.

Fall-out radiation would act on everyone for 30 years, and, at double the current rate, would contribute 200,000 man-rems.

Let us not be complacent about the seemingly low contribution from occupational exposure to our total dose. For the individual, it still amounts to

50 rems each 10 years, and this is five times higher than the average *per capita* dose for the whole population. It is however to be accepted, like any other occupational risk in industry; if one is unwilling to accept the risk, one seeks some other occupation. After all, one does not have to be a steeplejack or a coal miner—or a radiation worker.

The total from all sources is 9,800,000 man-rems, leaving a balance of roughly 4 million man-rems. Some of this balance will be consumed by the use of radio-active household devices, nuclear power, etc. However, it should not be used up simply because it appears to be there. Bear in mind that we must still operate on the principle that no radiation taken by man unnecessarily is good for him. Rather than try to use up our radiation reserve, we should endeavour, by all possible means, to increase it. With the pressures that there will be upon us to exploit new uses for radio-active materials, this will not be easy. But resist these pressures we must—within bounds of common sense and wisdom—if we are to continue to receive the bounties of our new servant.

ISOTOPES AND RADIATION ENERGY IN INDUSTRY

by

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The development of atomic energy has given us radio-active materials in two ways: first, by using spare neutrons in reactors, and secondly, by using fission products. These latter can be in the form of fission products circulating outside the reactor, or used fuel rods, or in the form of separated fission products, especially caesium-137 and krypton-85.

As the building of atomic power plants gains momentum, more and more fission products will be available, and their radiations may play a very important part in industrial development; this should be in full swing within the next five to ten years.

For some time we have been in the happy position of having radio-isotopes available in many forms and compounds, and industry has been busy applying them to its needs. The reasons why radio-active materials are of great benefit to industry are threefold. Firstly, radiations can be detected easily with modern instruments, and materials can be marked or labelled with radio-activity. It is possible, for example, to label a grain of sand and find it again, or to follow it for a long time. This tracing method is most important, as usually there is either no substitute for it, or only a very poor one. The detection of materials by this method is in many cases a million or so times better than by conventional analytical or spectroscopic methods. This has opened up research projects which could not have been envisaged before.

The second important type of application is based on the penetration or scattering of the radiations. Into this category fall the X-ray applications, as well as the instruments which have been developed for measuring thickness, and package monitors. Lastly, we can make use of the effects of the radiations themselves, particularly of their ability to ionize air or other gases, or, in the case of massive radiation (irradiation with big sources), to kill bacteria, change chromosomes, start chemical reactions, influence catalysts or pasteurize foods.

Let us first discuss the applications of isotopes in the form of sources of, say, up to 10 curies or so.

GENERAL PROCESS CONTROL

One can conveniently divide the industrial applications of radio-isotopes into two categories: those in which radio-isotopes have been incorporated into machines and can be used for general process control, and specialized applications particular to certain industries. In the first category we have materials which may replace X-ray equipment; a whole array of different gamma emitters is available for this purpose. We have cobalt-60 sources for taking gamma radiographs of steel of thicknesses up to 20 centimetres. We have iridium-192 or thulium-170 for radiographing less dense materials. Today these radio-isotopes are widely used in the form of small pieces of metal or metal oxides. They need no electricity supply and practically no maintenance, so that they are especially useful in the field, for instance, in checking the quality of welds of pipelines. The need here is for sources with higher specific activities, so as to use a point source of high enough intensity for reasonably short exposure times. Thulium, in particular, needs a higher specific activity than that produced so far in many countries. These higher specific activities can only be achieved in high neutron-flux-reactors, of the order of 10^{14} neutrons per square centimetre per second.

Some of the biggest savings in industry have been achieved by using thickness gauges which employ radio-active material. These instruments can be divided into two categories, according to whether transmitted or backscattered radiation is measured. The first type of instrument depends solely upon the absorption of radiation, and requires a source to be placed on one side of the material and a detector on the other. The greater the thickness of the material, the more radiation is absorbed, and the less falls on the detector. A very similar method can be used for checking packages. In this case the instrument does nothing more than radiograph quickly the top of the packages and ascertain if these are properly filled. Those that are not can then be automatically excluded. The control of liquid levels in closed containers also works on the same principle.

The backscattering type of instrument makes use of the fact that the proportion of beta particles scattered back by a thin sheet depends on its thickness and its atomic number. Thus, the thickness of a thin coat of tin applied to steel can be determined by comparing the amount of radiation scattered back by the coated steel with that scattered back by the bare steel surface. The scattering of gamma rays can be used for measuring thicknesses up to 2 centimetres of steel when only one side is accessible. This method has been developed for checking internal corrosion in pipes and tanks of an oil refinery. Use can be made of the fact that the reflected waves have a different wavelength from the waves originally emitted. By arranging that the detector is only sensitive to the reflected waves, one can dispense with all shielding and obtain a small and handy instrument. This method is extremely important,

for it obviates the necessity of shutting down the production process in order to check pipelines for corrosion.

Whenever insulating materials are processed in a relatively dry atmosphere, they become electrically charged. The induced charge often results from the friction between the material itself and parts of the machine. The presence of static electricity greatly increases the fire risk, and electro-static forces make the materials difficult to handle, thus disturbing the production process. It is therefore important that these charges, which are built up during the production process, should be discharged as quickly as they are formed. This can be done simply by making the surrounding air conductive for electricity. Usually beta particles from isotopes are used for this purpose. Alpha-emitting isotopes would give a denser ionization in a small volume, but there are no suitable alpha emitters of long half-life which are cheap and do not constitute an unnecessary health risk. The isotopes are usually in the form of metallic strips located near the place where the static charges occur. The simplicity of the method and the length of time for which these materials can be employed, together with the fact that they need no maintenance, make this an attractive proposition to the industrialist.

Beta-emitting materials have been used to excite luminescence. The radiations from tritium or krypton-85 are especially suitable, as they do not decompose the phosphor in the way in which the currently used alpha-emitters like radium do. Some emergency airfield markers have been made using beta-emitting isotopes, and it is claimed that they can be seen at night from a distance of $1\frac{1}{2}$ to 2 kilometres.

As for the specialized applications of isotopes, they are so numerous that it is only possible to mention a few of the more interesting ones.

SPECIALIZED APPLICATIONS

The efficiency of mixing can be checked by using small quantities of radio-activity to label one ingredient before the start of the process, and then measuring its distribution at the end of the process. If the distribution is homogeneous, a complete mix has been achieved. This type of application is especially useful when small amounts of one ingredient have to be mixed with large amounts of another. An example is the manufacture of cattle food to which small quantities of vitamins have to be added. Before the use of radio-isotopes it was almost impossible for the manufacturer to guarantee that each sack of food contained the right amount of vitamins. Incidentally, the amount of radio-activity added is small and, having a short half-life, it does not constitute a health hazard for the animals. A similar application is the labelling of glue to check its distribution in laminated building materials.

Similar methods have been very successful in checking from the outside of

the containing vessels the flow of bulk material in a factory. This technique is particularly useful in determining the characteristics of recycling. Radio-isotopes are also being used to determine the flow rates of large volumes of water, such as occur in hydroelectric schemes. It is already apparent that the method offers advantages of accuracy and ease of application over all conventional methods.

The motor industry now makes use of the precision in measuring small quantities of metals which can be achieved by means of radio-isotopes. A classic example is the investigation of wear in an internal combustion engine by using a radio-active piston ring. The radio-active debris carried away by the lubricating oil is then measured, and gives an index of the rate of wear. This method now replaces the older ones which were time-consuming and less accurate.

The oil industry employs radio-activity for a wide range of applications. Oil has to be frequently transported in pipelines, and when different grades of oil have to be sent through the same pipeline, it is a problem to know at the receiving end when a new grade is coming through, and also how much intermixing has occurred during the transport. This problem can now be solved in two ways. A small amount of radio-active liquid can be interposed between the two grades at the supply end of the pipeline. With a simple detection device at the receiving end, the arrival of the new grade can be recorded, and the degree of intermixing which occurred during the transport can be assessed. If the two grades of oil have a different density, which is usually the case, then a density-measuring instrument, very similar to the thickness gauge just described, can be used on the outside of the pipeline to give the operator a warning of the arrival of the new grade.

For some years now, well loggings have been made with sources containing radio-active materials. The reflexion of the radiations can be used to indicate the different strata surrounding the bore-holes. Recent advances in this field make it possible to assess the brine level in a bore-hole which may come up to a dangerous height during pumping operations. The development of this instrument, based on ideas we had a few years ago, has now advanced far enough for it to be used for operational purposes. A neutron source is let down into the bore-hole together with a gamma-ray detector, and when the neutrons hit the chlorine ions in the brine, unusually hard gamma rays are spontaneously emitted. These spontaneously emitted gamma rays can penetrate the concrete and steel with which the bore-hole is clad. By eliminating all radiations hitting the detector which have energies of less than say 10 million electron-volts, the instrument will only indicate the presence of chlorine ions. It is to my knowledge the only application of isotopes where neutron-induced promptly emitted gamma radiation is used for an industrial process.

For finding leaks in buried pipelines, a liquid containing isotopes can be used. The most modern method, also developed in the United Kingdom,

employs a diluted radio-active solution which is pumped through a pipeline under pressure. Some of the liquid will seep out of any leaks and become absorbed in the surrounding soil. The radio-active solution is followed by clear water which flushes out the pipeline and also drives a self-contained detector attached to a miniature recorder at a steady rate along the inside of the pipe. At the end of the pipeline the recorder is removed and played back; it will then give a record of radiation at the points of leakage.

The technique of auto-radiography has been known for a long time, but it has become a powerful method for investigating distributions on a microscopic scale. Coupled with the radio-active tracer technique, it has enabled progress to be made in the study of metals. The method can also be used in the study of paper manufacture. The distribution of the resins used can be shown by labelling them with sulphur-35. The migration of the resin can be demonstrated, and the effect of drying methods on the distribution of the resin, and therefore the quality of the product, can be measured.

A useful control method employing circulating catalyst beads under full operating conditions has been developed for catalytic crackers. In this process the incoming gas carries catalyst beads through a reactive zone where cracking occurs. The cracked gas then flows out of the plant but deposits the catalyst, which then flows through a furnace to burn off any coke deposited on it in the cracking process, and is then returned to the system. The flow rate of the catalyst, which is difficult to determine, is an important operating characteristic. By using a few beads each impregnated with a small amount of a gamma-active, non-volatile isotope, the flow rate can be determined by measuring the time taken for the tagged bead to travel between two rings of counters fixed some distance apart around the pipe leading to the furnace. Although the control is not, strictly speaking, continuous, a measurement is made frequently enough for adequate control.

By marking sand and mud either with scandium oxide or barium-140 baked on to the sand, we have been able to solve a number of siltation problems. The underwater tracing turned out to be fairly straightforward.

The safety of aircraft has been checked by adding radio-active material to the fuel in order to find out if any fuel spillage could be responsible for a fire or an explosion by bringing the fuel near a hot part of the engine.

Metallurgy has not only benefited from isotopes by measurements of wear or self-diffusion, but also by getting some otherwise elusive information needed for continuous casting processes. The shape of the solidification boundary in continuously cast aluminium can thus be determined.

Radio-activation analysis is widely used to detect tracer elements, and many industries are making use of this method. Considerable progress has been made in both chemical and physical techniques related to this method. On the physical side, great advantages have been gained by the use of scintillation counters as detectors. A simple single-channel pulse amplitude analyser

enables a plot of gamma ray energies to be made from an irradiated sample, from which various impurities can be distinguished on an energy basis. With an analyser of this kind, one can detect impurities in aluminium at levels of one part in 1 million or even in 10 million without any chemical separation. However, difficulties in making such an analysis arise from the fact that pulses coming from Compton recoil events have to be eliminated. Instruments have been built which do this by an anti-coincidence method. In this case the detector crystal is surrounded by another phosphor which responds to any gamma rays scattered out of the main detector. Unfortunately, however, such instruments are complex and very expensive.

For this reason a method has been devised in which the simple subtraction of two counting rates is used to eliminate the scattered radiations. Two scintillation counters, using respectively NaI-(Tl) and anthracene as phosphors are exposed to the source simultaneously. Their outputs are applied in rapid succession to a ratemeter in such a way that the counting rates are subtracted. Now the anthracene phosphor, consisting entirely of elements of low atomic number, produces very few photo-electric pulses and can thus be used as a compensator to reduce the effect of Compton recoil.

This subtraction principle, although it slightly increases the statistical fluctuations obtained, is capable of wide application. It is also being used in the analysis of radio-active materials in the presence of other, known species. This is done simply by the subtraction of responses of two identical scintillation counters, one counting the mixture and the other a preparation of the known contaminant.

FUTURE PROSPECTS

No attempt has been made here to assess the financial benefits of radio-isotopes to industry. A separate lecture by Dr. Libby deals with this aspect. Nor has anything been said about industries connected with agriculture, which are treated in another lecture. But there is no doubt that industry today is making wide use of radio-activity; in fact, one can hardly buy a finished product which has not had something to do with radio-isotopes in some form of process control. And this is only the beginning of the use of radio-active materials in industry.

Fantastic amounts of gamma-emitting materials will become available in the coming years. Scientists of many countries are busy finding uses for this entirely new source of energy. Many atomic power stations will be built, and the gamma energy locked up in these stations will be enormous—something like 2 per cent of the power could be available as radiation. In fact, future power stations may well be built with a view to using this locked-up radiation energy. In the meantine, we have the choice of utilizing either used fuel rods

of conventional power stations—a not very satisfactory solution because of difficulties of transport and cooling—or one of the long-lived fission products after it has been separated. Here, caesium-137 may become the most important isotope, and plans are on foot in several countries to extract this element.

However, the supply of caesium will not be unlimited, even in the future. It should be remembered that for each thousand megawatts of heat produced in an atomic power reactor, something of the order of one megacurie of caesium-137 is obtained per year. In a country like the United Kingdom, it is therefore unlikely that more than, say, hundreds of megacuries of caesium will be produced per year in the next twenty years. If bigger sources are needed, it will be necessary to fall back on the gamma energy in reactors. Until caesium becomes available in bigger quantities—a development which we do not expect to start before 1960—bigger cobalt-60 sources will have to be used, although there is no doubt that, ultimately (say from 1965 onwards), caesium will become a very cheap source of radiation energy.

Radiation energy is being envisaged for such vastly different types of applications that the source strengths required are spread over a very wide margin. Whilst potatoes may be irradiated with doses of less than 10^4 roentgens in order to prevent sprouting, the vulcanization of rubber will need something like 10^8 roentgens. Thus small sources as well as big sources, like reactors, will have their part to play. From the point of view of radiation production, the future can be seen as follows. Machines like Van de Graeff's, or linear accelerators, will be used when small volumes have to be irradiated with relatively high doses. Caesium, cobalt or fission products generally will be used for all main applications where the dose does not exceed 10^5 to 10^6 roentgens. For higher radiation doses and large scale production, the gamma-rays from reactors will have to be used. It is likely that the fission products will have to be circulated outside the reactor itself and their gamma radiation will be used in a factory attached to the reactors for, say, the vulcanization of rubber tyres or other chemical changes where high doses are needed.

The whole research and development of the use of radiation energy is of course in its infancy, and some countries are now making a serious effort in this field. In the United Kingdom, we are concentrating all radiation sources on one site, where scientists from industry and the U.K. Atomic Energy Authority are working side by side to solve these problems. Let us take a look into the crystal ball and see which fields seem most promising for the use of radiation energy.

CHEMICAL PROCESSES

Radiation might be used for many industrial processes ranging from those in which the physical properties of a material are altered by radiation to those in which complete syntheses can be carried out. Let us first consider some important physical changes which can be produced by irradiating various materials. Radiation can act in two ways; firstly, by modifying the properties of finished polymers, and secondly—when used in the manufacturing process—by actually producing a polymer with superior high temperature properties. An example of the first application is the effect of radiation on polyethylene. This material normally melts at approximately 110°C. At 100°C. its tensile strength is reduced, and pipes made of this material cannot safely be used with boiling water under pressure. Irradiation of polyethylene with a dose of between 5×10^7 and 2×10^8 roentgens prevents the material from melting; when the temperature is raised it merely softens. It has already been found that irradiated polyethylene cable can be used at temperatures of 140°C.-150°C. Some financial saving may accrue from the use of irradiated polyethylene cable, since more current can be passed through the conductor without melting the insulator.

The second way in which the use of radiation may be of importance is well illustrated by the vulcanization of rubber. The chemical vulcanization of rubber is normally carried out by using sulphur. The process is one in which the rubber molecules are joined together by sulphur atoms. Radiation has a similar effect on rubber in that it, too, can cause these molecules to join together by carbon-carbon bonds, no sulphur being necessary. Moreover, the high temperature properties of the material vulcanized by irradiation are markedly superior to those of chemically vulcanized rubber. For example, embrittlement of some acrylate rubbers takes place in eight hours at 350°F. with the chemically vulcanized material, but does not occur until after 36 hours with the radiation vulcanized material.

Another interesting physical change is the effect of radiation on transistors. The performance of this new radio valve can be markedly improved by radiation, particularly where the transistor is used in high-speed circuits, such as those employed in digital computers.

There are, of course, many other chemical reactions besides vulcanization which can be triggered off by radiation. Among the most important are those in which one active molecule causes the reaction of a large number of inactive molecules. These reactions are known as chain reactions, and are usually employed in polymer production. Normally, active molecules are added to the inactive molecules in the form of a catalyst. With radiation, however, active molecules can be produced from normally inactive ones, and, as a result, polymerization induced by radiation can often take place under physical conditions which are quite different from the normal catalytic

process. For example, polymerization of ethylene to produce the plastic polythene, which is used to make household articles, is normally carried out at a pressure of over 1,000 atmospheres and a temperature of 200°C. If radiation is used to initiate the reaction, polymerization can be carried out at pressures very little above atmospheric and at ordinary temperature, and the process yields a product which is rather tougher than that produced by the high-pressure process. This is just one example of the way in which the use of radiation leads not only to a product differing from that normally obtained, but often to one having superior properties. This field of the initiation of chemical reactions is one in which a considerable amount of work is being carried out.

BIOLOGICAL PROCESSES

Opportunities for the industrial use of radiation in sterilization procedures are very great. A sufficiently large dose of radiation can kill most forms of living organisms. Drugs can easily be exposed to doses of this order, and the total chemical change produced by this radiation is almost negligible. Moreover, a dose of this magnitude results in a rise in temperature of only 1° or 2°C. Hence any damage to the product which might be produced by heating is entirely eliminated. Heat-sensitive drugs, which at present are sterilized by filtering off the bacteria with subsequent aseptic sub-division of the bulk solution, are therefore particularly suited to sterilization by radiation. Moreover, the filtration method does not eliminate the possibility of chance contamination during the aseptic sub-division, whereas sterilization by radiation can be carried out in the final package. In fact, it offers the same degree of sterility that heat treatment gives to materials which are not thermally sensitive. It has been shown that anti-biotics such as penicillin, streptomycin, aureomycin and terramycin can be sterilized by radiation without any loss of potency. This work has been extended to the sterilization of surgical dressings and even to bone and artery sections for grafting.

Hypodermic needles can, of course, be sterilized by heat and then packed in sterile plastic envelopes. However, the reliability of the sterility is improved if the sterilization process is performed after the hypodermic needle has been sealed in its container. Packaging of this kind is of special advantage in emergency packs which may have to be used under conditions where there is no sterilizing equipment. The same considerations apply to burn dressings and sutures, but with the additional advantage that some burn dressings are heat sensitive, and that the strength of some sutures may be reduced by heat sterilization.

When hospital bedding is laundered, it is still far from being free from spores and bacteria which can cause infection. In particular, the bedding

from surgical wards often requires treatment in a steam autoclave. Unfortunately, woollen blankets may be ruined by two or three treatments in an autoclave, and so an unhappy compromise is usually struck between economy and sterilization. But by using irradiation, blankets can be sterilized without an appreciable rise in temperature, and although there is some slight damage to the fibres, an average blanket can survive as many as 20 sterilizations by radiation.

The inactivation of a virus in order to produce vaccine must be carefully controlled, so that the infectivity is destroyed without seriously reducing the anti-genicity, which is the power of the inactivated virus to stimulate the generation of antibodies in the patient. Inactivation is more commonly carried out by chemical means, but in many cases the margin between successful inactivation and reduced anti-genicity of the vaccine is narrow. There is some evidence to show that radiation-induced inactivation can be achieved without the same relative damage to the anti-genicity.

There are many ways in which atomic radiation may be used to help in the preservation of food. Perhaps the simplest of these, and one requiring a small dose, is the prevention of sprouting of potatoes. The lowest doses appear only to delay the sprouting, and potatoes thus treated are suitable for shipping as seed to far-away places such as South Africa and Australia. At present the seed potatoes which have to pass through the tropics on their way to those places suffer from the rise in temperature, which induces premature sprouting. A slightly larger dose will delay sprouting of potatoes harvested late in summer until the following summer or even later. One of the early experiments showed that potatoes irradiated in this way were more susceptible to damage by bruising because they had lost their power of healing. However, if the potatoes are allowed to rest a few days before treatment, their skins are already hard enough to enable them to stand up to normal handling.

Serious losses occur in grain stores from the multiplying hosts of grain weevils and beetles, especially in warm and humid climates. The dose necessary to kill the insects within a few days is very much higher than that required to sterilize both insects and their eggs from a genetic point of view. Fortunately, this latter treatment is adequate in most cases. Radiation treatment is also being investigated for a range of packaged food products, including spices and dried fruits, and for increasing the storage life of certain foodstuffs.

Another approach towards the food problem is that of breeding more profitable strains of crop plants. By irradiating seed or pollen, it is possible to increase the number of mutants by a factor of ten or more. Such an increase is of value when studying the resistance of mutants to some disease, because the selection process is much simpler than that required in normal plant breeding. All the mutants of the first generation are cultivated, and the

resulting seed is collected and inoculated with the virus from which immunity is being sought. The treated seeds are sown, and those which prosper are obviously the most resistant. There still remains the problem of determining whether the characteristics of the mutant are good in other respects, such as crop yield and resistance to weather.

For normal plant breeding there is no great difficulty in obtaining sufficient starting material without much assistance from artifical radiation. But in some cases radiation can be valuable. It has been shown, for example, that in some instances two strains which are otherwise incompatible can be made compatible by irradiating the pollen of one and applying it to the stamen of the other. This technique has tremendous potential value, and a good deal of experimental work is going on along these lines.

Quite apart from the speculative developments mentioned here, there are still others which might revolutionize a whole industry. For instance, the influence of radiation on certain chemicals may have an effect which might prove to be the starting point of a new chemical industry.

To sum up: we have so many good horses in our stables that some of them are bound to win. Therefore the so-called 'waste products' of atomic energy will be greatly sought after by industry in the next five or ten years. In fact, there may be a serious shortage of radiation energy, and the earlier we can muster all available gamma energies—such as cobalt sources, separate fission products or unlocked neutron-free gamma rays in reactors—the nearer we are to fulfilling the demand which industry is bound to make within the next few years.

THE SIGNIFICANCE OF ATOMIC ENERGY FOR FOOD AND AGRICULTURE

by
R. A. SILOW

Dr. Silow, a British geneticist, is Chief of the Atomic Energy Branch in the Agriculture Division of the Food and Agriculture Organization of the United Nations.

The fact that Dr. Libby has spoken before me this evening provides me with a very appropriate introductory theme for my address. Speaking at a conference just over a year ago, Dr. Libby made a most interesting evaluation of the economic potential of atomic energy for agriculture and food production in the U.S.A., on much the same lines as his survey of the contributions of atomic energy to industry this evening. As a result Dr. Libby came to the striking conclusion that the potential contributions of atomic energy to agriculture could be of approximately the same order of magnitude as its contribution to the generation of electric power. That Dr. Libby was speaking in his official capacity as a Commissioner of the U.S. Atomic Energy Commission—a body which is devoting so much attention to the use of atomic energy for electric power production—gives particular significance to his conclusion.

With that authoritative statement as a background, I propose this evening to undertake a brief survey of the significance of atomic energy for agriculture and food production. This survey cannot be exhaustive, for the subject is enormous—as enormous as that of agriculture itself. The papers presented at this conference have shown that radio-isotopes impinge upon all aspects of biological research—and all aspects of biology are, of course, of fundamental significance for agriculture and food production. In addition, other aspects of atomic energy, such as radiation and power, are also of immense potential significance for agriculture, so that the field to be covered is wide indeed.

ATOMIC POWER IN AGRICULTURE

The primary aim of current industrial atomic energy programmes is to produce electric power at a cost that will compare favourably with other methods using more conventional sources of energy, such as coal, oil or water power. So far as agriculture is concerned, it appears that this power aspect of atomic energy is likely to be the least important in the immediately

coming years. It may of course be confidently expected that atomic-generated electric power will eventually make possible a more plentiful supply of reasonably priced current in rural districts. This would lower costs of production through farm electrification and the substitution of mechanical processes for human effort, and would raise living standards of rural peoples by making modern domestic conveniences and comforts more widely available in country districts. These factors will be of significance, not so much from the standpoint of reducing the flow of labour from the land as in raising the efficiency and happiness of those who remain in farm employment. It must however be recognized that the impact of more plentiful electric power in rural districts must necessarily await the widespread application of nuclear power in industry.

Other applications of nuclear power in agriculture are rather speculative at this present time. It has, for instance, often been said that nuclear energy, through the provision of cheap and abundant power for pumping water in irrigation schemes, could make the deserts bloom, but it must be realized that the settlement and development of previously uncultivated areas would require huge capital investment and constitute an extremely complex social undertaking in which the actual cost of power would probably be one of the less important factors. It is, of course, conceivable that the availability of power from nuclear sources, in cases where it could not easily be provided from conventional resources, might be a determining factor in whether a particular development project could be undertaken at all; but it appears likely that, in general, population pressures will have to be a great deal higher than they now are before we shall be compelled to look to such schemes to ease the supply situation. In the meantime, food supplies could more easily be increased by measures to raise the productivity of land already under cultivation, and by reducing the losses that occur from the attacks of pests and diseases on growing crops and livestock and in food stocks during storage and distribution.

It is here that the two other aspects of atomic energy, radiation and radio-isotopes, are of great promise and may well in the long run prove to be of at least as great significance for man's future welfare as the more spectacular and obvious contribution of atomic energy to the production of electric power.

RADIATION AND FOOD PRESERVATION

The characteristic of radiation which is of interest in connexion with food and agriculture is its ability to penetrate biological tissues and induce changes in them. These are essentially destructive changes, which in the extreme case result in death. One of the first potential applications of radiation to be

investigated was therefore whether it could be used to kill insect pests infesting growing crops and livestock in the field or in stored grain or cereal products, or to sterilize or pasteurize perishable foodstuffs, such as meat, by killing the bacteria on them.

A great deal of the interest in this method of food preservation arises from the wide scope that it offers for the useful employment of the radio-active by-products of the operation of nuclear reactors—the so-called radio-active wastes. In addition, as a parallel development, radiations of certain types can also now be provided at high intensity by electrical machines.

The use of radiation for preserving foodstuffs appears particularly attractive because it can be used at low or normal temperatures, thereby avoiding the changes in digestibility and palatibility associated with the common method of preservation by heating. The use of radiation thus opens up the possibility of a wider distribution of perishable foodstuffs in the fresh or near-fresh state. However, it has been found that radiation itself can lead to other kinds of undesirable changes in flavour, texture and appearance, and methods of minimizing these by special procedures or by the use of special protective substances are now under extensive investigation in many laboratories, especially in the U.S.A. Animal feeding experiments and tests with human volunteers conducted to determine whether irradiated foodstuffs are safe to eat have so far given no indication of adverse effects of any kind; nor has there been any evidence that their nutritional value is affected in any important way. Whilst this method of preservation appears to be quite promising for certain kinds of meat, poultry, fish, fruit and vegetables, questions of costs and methods of handling large quantities of material on a commercial scale remain to be considered.

Thus radiation appears to be particularly promising for the destruction of insects in stored foodstuffs such as grain, cereal products and dried fruits, and for the extension of the storage life of potatoes and root crops by suppression of sprouting; but the relative cost of treatment by irradiation as compared with other simple and effective processes that are available will need to be carefully examined under local conditions. Present indications are that radiation will have its greatest potentiality with meats and other high cost products, including certain fresh fruits and vegetables, which can absorb the added expense more easily than low cost foods, and with speciality products such as packaged cereal products and dried fruits.

Because of its requirements for proper technological control, continuous mechanized processing and packaging, and rapid and efficient distribution, the use of radiation for food preservation will have its greatest interest for countries having a mature industrial economy and a highly organized system of food distribution. It is quite unlikely that irradiation will entirely replace other methods of food preservation such as refrigeration, heat sterilization, or the use of chemical preservatives, in the foreseeable future, but it will

probably come into use gradually as a supplement to them under suitable conditions and for appropriate purposes. As an example, the possibility is being investigated of giving the rather slightly salted bacon that is now popular in many countries a light supplementary treatment by irradiation to increase its storage life.

It is difficult to say just how soon irradiated foodstuffs will be on the market. There are still very many problems to be solved, but the extensive research and development programme in progress in the U.S.A. is expected by about 1960 to give a clearer indication on this subject. Nevertheless, it can be said even now that irradiation undoubtedly appears to have promise for particular types of food and under particular conditions. If this is substantiated, irradiation will make an important contribution to food supplies. In the meantime it is important to remember that radiation will certainly not obviate the need for the development of other conventional methods of food preservation, such as canning, the use of chemical preservatives, dehydration and refrigeration, all of which are recognized as having specific advantages for particular kinds of foods and also at particular levels of economic and technological development.

The confidence of the U.S. Government in this new method of food preservation is evident from the very substantial financial support that it is giving to research in this subject. Whilst many other countries are keenly interested in the potentialities of this new technique, few of them are likely to be in a position in the near future to undertake investigations independently on an adequate scale, for research in this subject is expensive and requires the services of highly skilled and well trained scientists in many disciplines. This is therefore a field in which advance is most likely to be achieved through international co-operation, and such co-operation could most appropriately be initiated in Europe. Accordingly, the Food and Agriculture Organization is planning to convene next year a meeting of European specialists to give consideration to specific means of developing practical co-operation in research in food preservation by irradiation in Europe.

RADIATION AND PLANT BREEDING

An application of radiation of a quite different nature is that involved in connexion with the breeding of improved varieties of plants and animals. It has long been known that radiation such as X-rays can cause heritable mutations in plants and animals, and with the advent of atomic energy further kinds of radiation and more potent sources have become freely available for experimental use. Whilst the vast majority of mutations induced by radiation are deleterious, desirable types occur in low proportion and have been selected in a wide variety of crops.

This method of accelerating plant breeding is already under investigation in many countries. The technique is not so readily applicable to livestock improvement because of the greater difficulty of experimentation involved, but the possibility of developing by this means strains of poultry with a higher egg production is already under investigation in the U.S.A. So far as plant breeding is concerned, however, practical accomplishments in the development of improved varieties of crop plants have already been achieved. Thus a strain of oats resistant to one of the most damaging rust diseases in the U.S.A. has been developed by this means. In Sweden stiff-strawed types of barley have been obtained which have improved standing ability and are therefore better able to make economic use of fertilizer dressings, and which are particularly suitable for mechanical harvesting. The widely grown variety of white mustard in that country, with improved yield and higher oil content, was also developed by irradiation, as well as a variety of cooking pea with higher yield. As an example of the economic return from even one such successful accomplishment, it is of interest that the white mustard variety is the only one grown in Sweden, and the value of the crop is about 2 million Swedish crowns, which is more than eight times the total annual government allocation for all mutation research work in that country.

Since the possibility of using radiation-induced mutations in plant breeding was first considered, there has been much controversy as to their practical value, chiefly on the grounds that the changes induced by radiation are essentially destructive in nature. However, the examples which have been quoted, and much other experimental material still under investigation, leave no room for doubt that induced mutations can be obtained that have a favourable effect on such important features as yield, rate of maturity, standing ability, disease resistance, and various other important characteristics.

Beyond this, however, the most exciting implication of this work lies in the possibility that through the use of radiation the plant breeder may be able more directly to control the mutation process. Mutation has generally been considered to be entirely at random, but gradually accumulating evidence suggests that the various forms of ionizing radiation differ in the range of mutations that they induce. In this connexion it is noteworthy that ultraviolet light, a non-ionizing radiation, can also induce mutations, and an ever-increasing number of chemicals are also being found to have this property. The artificial induction of mutations by radiations is only in its infancy, and much more work needs to be done before its potentialities can be fully evaluated. It is well worth doing, because the artificial induction of mutations provides the one hope for freedom from complete dependence upon nature for the genetic variations needed to improve crop plants and to adapt them to the ever-more stringent demands that are made upon them. With these possibilities in mind, and remembering that plant breeding is one of the cheapest and surest ways of increasing food production, it is justifiable

to predict that the use of radiation to develop improved varieties of crop plants will in due course rank amongst the most valuable of the contributions of atomic energy to the welfare of mankind.

One word of warning, however, is needed in this connexion. It should be remembered that few countries, developed or underdeveloped, have adequately exploited the breeding material already present in their native crops or in those that could easily be introduced from other parts of the world. It is important therefore, especially in countries with a limited number of scientists, that plans for the use of radiation in plant breeding should not be at the expense of an effective plant breeding programme conducted on a conventional basis.

ISOTOPES AS TOOLS OF BIOLOGICAL RESEARCH

We now come to the third and last aspect of atomic energy—radio-active isotopes. Their particular value to agriculture is not as direct aids to production, but as indirect aids, through their use in research—research that can lead to greater efficiency and economy in production and utilization of food and other agricultural products.

Radio-isotopes are of especial value in studying the physiology and chemistry of living organisms and of complex dynamic biological systems such as those involved in the relationship between soil, plants, animals and man. The ready availability of radio-isotopes has made possible advances in biological research that are comparable with those which followed the discovery of the microscope; as highly refined research tools they are now giving information that could be obtained in no other way or only at much greater expense in time and money.

It may in fact be said that the more complex and recondite the system under investigation, the greater is likely to be the value of radio-isotopes in studying it as compared with the use of conventional physical and chemical research techniques. One extremely important achievement resulting from the use of radio-isotopes is that now, for the first time, it has become possible to follow directly the movement of substances into or out of a system in dynamic equilibrium, or to identify movement that is contrary to the apparent over-all direction. By thus improving our knowledge of the basic biological principles involved in growing crops and livestock, radio-isotopes are leading to the development of improved techniques and greater efficiency in the production of foodstuffs.

Obviously in the short time at my disposal it will be impossible to refer to all of the myriad agricultural investigations in which isotopes are being successfully used, and only a few examples can be given. Thus in studies of soil fertility and plant nutrition, the use of radio-isotopes is leading to the

development of more suitable methods of application of fertilizers which will result in greater efficiency. Fertilizers are expensive, and their present limited usage in many countries is almost entirely a question of economics. Information on the way in which they are used by plants, and how they should be employed in order to ensure the fullest possible return, will therefore be of great significance in encouraging their wider use. Taking the conservative figure of 1 per cent greater efficiency on the present annual usage of about $1,000 million worth of fertilizers in the U.S.A., this could mean annual savings of at least $10 million in that country alone. The economic implications across the whole field of fertilizer usage the world over are therefore immense. It is important to note that much of the research needed will have to be carried out under the local soil and climatic conditions under which its findings are to be put into effect, and for much of this work radio-isotopes provide the best or only possible mode of attack.

Isotopes studies are also showing how more efficient insecticides and fungicides could be developed; the magnitude of practical contributions of this type can be judged from the estimate that if better insecticides and fungicides were available, the yields of many crops in various countries could be increased by at least 25 to 30 per cent, and sometimes even doubled.

Through the use of radio-isotopes remarkable progress has also been made in the elucidation of the mechanism of photosynthesis, the process by which green plants utilize energy from the sun to convert carbon dioxide and water into sugars, which are then synthesized by the plant into starches, fats, amino-acids and proteins. This process is the very foundation of our agriculture, and we are dependent upon it for all our food, timber for shelter, fibres for clothing, and for the conventional fuels, including the fossilized fuels—coal and oil—that have originated from the products of photosynthesis in long past ages. Photosynthesis is without doubt the largest and most fundamental single chemical process on earth. Yet the efficiency of utilization of solar energy in this process in our major crop plants is of the order of only 1 or 2 per cent. With the fundamental knowledge of the mechanism of photosynthesis now becoming available for the first time through the use of isotopes, it may be anticipated with confidence that we shall eventually be able to increase the efficiency of this basic process.

Radio-isotope techniques are also giving much impetus to investigations of the basic problems of nutrition, physiology and pathology involved in animal production. They have been used, for instance, in fundamental studies of protein synthesis in the animal body, and with outstanding success in studies of the complex biochemical and physiological processes involved in lactation. They have also been very effectively employed in studying the efficiency of food utilization by animals, and are of particular value in studies of the metabolism of minerals, including the micronutrients or trace elements that are essential for animal health.

Radio-isotopes can also be extremely helpful in enhancing the contribution of research to the development of world fisheries, which are a most important source of animal protein in human diet.

Finally, radio-isotopes also have important applications in the study of human nutrition. Their use in man has been somewhat limited up to the present, but work has already been done in connexion with fat and protein metabolism, and mineral nutrition. Much knowledge gained from animal studies is also of course applicable to man. Such knowledge will help in the development of adequate and properly balanced diets which are so important for health and efficiency.

It should be emphasized that no brief survey such as has been attempted here can do justice to the immense potentialities of radio-isotope techniques in research in agriculture and related fields. What is particularly important about them is that they can be just as valuable for some kinds of applied research on essentially practical problems as they are for some of the most abstruse fundamental investigations. The research applications of radio-isotopes are therefore something from which all countries can benefit immediately.

THE NEED FOR AGRICULTURAL RESEARCH

However, radio-isotope techniques are not needed in every investigation, and they certainly do not make traditional research methods obsolete. They will in fact make their most effective contribution against a background of mature experience in general research. Yet they are of such special value that they should be available for use in all appropriate investigations.

The very great contribution that atomic energy, through the use of radio-isotopes and radiation as research tools, will make to world food production cannot be over-emphasized. We have seen in our lifetime how scientific and technological research applied to industry on a vast scale in the U.S.A. over a few decades has made that country the foremost industrial nation of the world.

Research is just as important for agriculture as it is for industry. In fact it is even more important for agriculture, because agriculture is based on biological materials and biological processes, which are far more difficult to understand and to control than the chemical, physical and mechanical processes involved in industrial production. Furthermore, agriculture is the world's largest primary industry, and every man, woman and child has a vital interest in its welfare—not only because the fullest possible application of all scientific knowledge will be needed if the world's rapidly growing populations are to be adequately fed, but also because a healthy agriculture is an essential element in the national economy as a whole.

Although many research accomplishments are somewhat unspectacular, the numerous small advances in food production techniques to which they lead are in total very important, for they can make the difference between only just covering production costs, and having a substantial margin in hand. In the one case this means marginal subsistence of the rural worker; in the other case it means a satisfactory standard of living for him, with sufficient purchasing power left over after his basic requirements are satisfied to enable him to purchase the products of urban industry. Thus there is a close interdependence between the development of agriculture and of urban industry.

It is significant that the importance of research for agriculture is widely recognized in such major food-producing countries as the U.S.A. and the U.S.S.R., and in many of those countries of Western Europe where agricultural productivity is already exceptionally high. These countries are already taking steps to apply atomic energy techniques in their research programmes on a substantial scale. For the economically underdeveloped countries agricultural research is equally important, not only because it is there that the most explosive population increases are likely to occur, but also because most of those countries are located in either the humid tropics or the arid and semi-arid regions of the world, where agricultural problems have so far had much less attention from scientists than in temperate countries.

Fortunately cost should present no serious obstacle to the use of radio-isotopes in research, since these and the associated equipment needed are relatively inexpensive. In fact, it is not shortage of funds or non-availability of isotopes that are the limiting factors, but the shortage of trained investigators with experience in these techniques. However, training in the use of isotopes can be acquired in a few months, and training courses organized by the governments of the U.S.A., the United Kingdom and the U.S.S.R. which have been made available to students from other countries have done much to diffuse knowledge of these new techniques. Such training courses are of considerable value to agricultural scientists; the Food and Agriculture Organization is planning to organize, as soon as facilities are available, a radio-isotopes training course specifically designed for the agricultural research worker and intended particularly for investigators from countries with less general experience in agricultural research. In this and other ways FAO is planning to assist governments to translate into realities the immense potentialities of atomic energy.

As is the case with all man's activities, the extent to which the promises of atomic energy for food and agriculture materialize will depend ultimately upon the investment and effort put into research. If this need for research investment and effort is adequately recognized by governments, the contributions of radio-isotopes and radiation to increased food production and improved levels of nutrition can easily be the first practical benefit of atomic energy for the greater part of the world's population.

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of science on society

Vol. VIII (1957),
No. 4 [A] Price per copy: $ .50; 2/6 (stg.); 125 fr.

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NS 57 I 29A

UNITED NATIONS EDUCATIONAL, SCIENTIFIC
AND CULTURAL ORGANIZATION
19 Avenue Kléber, Paris-16e, France

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